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IMPROVEMENT OF DRYING AND REHYDRATION CHARACTERISTICS OF HASH-BROWN POTATOES

by

M. SADIQ NARGAL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **IMPROVEMENT OF DRYING AND REHYDRATION CHARACTERISTICS OF HASH-BROWN POTATOES** submitted by **M. SADIQ NARGAL** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** in **FOOD PROCESSING**.

.....

Supervisor

.....

.....

Date April 12, 1985

Dedicated to

my beloved Grandmother

ABSTRACT

Slow rehydration rate, brown discoloration and excessive breakage on handling are common problems associated with dehydrated potatoes such as hash-browns. In this experiment, attempts were made to increase the rate of drying so as to minimize the problems associated with case-hardening, shrinkage and browning of hash-brown potatoes and hence improve the rate of rehydration and some sensory characteristics and reduce loss due to breakage.

Effects of some physical and chemical pretreatments were studied. In the proposed process, potato shreds approximately (12.7 - 38.1) x 8 x 1.5 mm in size were precooked in $CaCl_2$ (200 ppm as Ca^{2+}) solution, steam cooked (10 min), dipped in glycerol (5%) and surfactant (0.1%) emulsion, and then dried in a fluid bed dryer. The following improvements were obtained : The drying rate was increased through the extension of the constant-rate period and the total drying time was shortened to about one hour. The product had lower bulk density (0.15 vs 0.31 g/cm^3) and was fully rehydrated after 20 min in boiling water as compared to > 30 min for a commercial product. The rehydration ratio (R.R.) of the treated sample was 6.3 as compared to 4.6 of the commercial sample. The color of the product was lighter (L = 75.4 vs L = 69.2) and breakage on handling was also reduced from 19.3% (control sample) to 3.6% (sample produced with the proposed process).

Overall acceptability of the experimental product was found to be comparable by sensory panels to that of hash-browns prepared from fresh potatoes and from a commercial dehydrated product.

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1. INTRODUCTION

1.1 Potato Products and their Importance

The potato (*Solanum tuberosum*, L.) is considered one of the world's most important staple foods ranking only behind rice, wheat and maize. Approximately 300 million tonnes are harvested annually in 130 countries (The IDRC Reports, 1985). In North America, the production of potato has increased substantially in recent years, partly due to high yielding varieties and partly to improved farming techniques.

Dehydration is one of the common methods for economical preservation of the potato crop. Dehydrated potatoes are becoming more popular because of their increased utilization both as culinary products and processed raw materials. They are used in dry soup mixes, ready meals, processed meats, stuffings, snacks, baby and pet foods. Dehydrated food products offer many advantages in packaging, shipping and storage since they are cheap to pack, light in weight, easy to store and require no refrigerated storage.

The summary of production of potatoes for 1982 and 1983 is shown in Table 1. From economic point of view, 251 million dollars worth of potatoes (Selected Agriculture Statistics for Canada and the Provinces, 1982) and approximately 23 million dollars in value of potato products (Statistic Canada, 1982b) were produced in Canada in 1982. Potatoes amounting to 25 million and 30 million dollars, were grown in Alberta in 1982 and 1983, respectively. Of all potatoes grown in Alberta, 65% are processed (Horner 1980), the remainder being consumed fresh for table and seed purposes. There are five potato processing plants in Alberta mainly producing chips, French fries and granules. The following is the apparent per capita consumption of potatoes in kg/year for Canada (Statistics Canada, 1982a):

1981	64.79 kg/year
1982	69.72 kg/year

Table 1

Area, Average Yield and Production of Potatoes, 1982 and 1983[1]

	1982			1983		
	Area ('000 ha)	Yield (Kg/ha)	Production ('000 MT)	Area ('000 ha)	Yield (Kg/ha)	Production ('000 MT)
World	20,320	13,974	283,955	20,167	14,205	286,472
USA	515	30,964	15,958	501	29,465	14,774
Canada	113	24,702	2,799	113	22,352	2,520
Alberta[2]	7.3	26,341	≃192	7.5	26,663	≃200

[1]FAO, Bulletin of Statistics, 1984

[2]Agriculture Statistics Yearbook, 1983.

It is believed that the upward trend in potato consumption is due to increasing consumption in restaurants and fast food outlets.

In view of the fairly high production of potatoes, there seems to be good potential for the production of different new forms of dehydrated products such as cubes, slices, shreds, granules and rice.

1.2 Major Problems Encountered on Drying

There are many problems encountered on dehydration of potatoes some of which are listed below :

1.2.1 Slow Drying Rate

Dehydration rate affects physical properties of the dried products. In general, the faster the drying rate, the lower the bulk density and, also, the faster the rehydration rate. Slow drying rate results in high energy consumption and, often, inferior products. It is important that most of the drying be accomplished in a "constant-rate" phase, meaning constant-rate of evaporation per unit of surface area per unit time. In many cases of food dehydration, constant-rate period is short and most of the drying is done at continually decreasing rate (falling-rate phase). If the product can be dried rapidly in the begining of the drying process when the moisture content is high, then it is possible that product continue to dry rapidly later when the moisture content is low (Kueneman, 1975). In such cases the falling-rate period is short and, therefore, total drying time will also be shorter.

1.2.2 Shrinkage of the Product

Tissue of potatoes and other vegetables possesses the property of "turgor" as the cells are distended by their contents and the elasticity of the cell wall. Upon drying under unfavourable conditions, structural damage and deformations result from shrinkage effects such as surface cracking, shearing and crushing in the dried tissue. These types of products, on

rehydration, are unable to recover their original shape and size. This is partly due to the destruction of semi-permeable membranes causing leaching of solutes from the cell and the loss of turgor.

1.2.3 Case Hardening

One of the problems that may be encountered in dehydration of certain vegetables is "case hardening". This happens when the outer tissues of thick sliced or diced vegetables dry more rapidly than the inner tissue and forms a dry external layer. This hardened layer resists the flow of moisture from the interior to the surface during the early stage of dehydration, resulting in long drying rate, unattractive appearance and color, and slow rehydration.

1.2.4 Fragile Texture

Some of the dehydrated products, especially when prepared in the form of thin slices and shreds, tend to be fragile. This causes loss of product in packaging and handling. Fragile texture of dehydrated products depends upon many factors such as type and composition of raw materials, piece thickness, preparation method and rate of dehydration. Thin sliced products of porous texture would be more prone to breakage. Such fragile vegetable products pose problems in packaging, transportation and storage. Too much breakage of the pieces in the package, would certainly reduce the consumer preference for the product. Hence, extreme care and special packaging would be required to maintain the quality characteristics.

1.2.5 Poor Rehydration Characteristics

The rehydration process, that is, replacing of water in dehydrated foods, is not a simple reversal of the drying mechanism. In dehydrated potato products elasticity of the cell walls and starch contents are both important for good rehydration. The changes in their properties are induced by heat treatment. Some pretreatments and modifications of dehydration conditions have been found to be helpful in effecting fast and more complete rehydration.

1.2.6 Color Changes

Another problem commonly observed in dehydrated product is the color change called "browning", that may be due to heat damage and chemical reactions. Long dehydration time and high temperature and unfavorable conditions are partly responsible for color change. Heat damage adversly affects flavor, rehydration characteristics and nutritional content of the dehydrated product. For most of the dehydrated potato products (slices, cubes and granules) a light color is desirable. Enzymatic browning (tyrosine-tyrosinase oxidation), after-cooking darkening (oxidation of complexes between ferrous iron salts and o-diphenols) and non-enzymatic browning (maillard or browning reactions involving inter-relationship of proteins, carbohydrates, pH, moisture, temperature and time) are important in the color development of dehydrated potato products.

1.3 Objective of the Present Work

Keeping the drying problems in view, the present work was undertaken to improve:

1. Drying rate,
2. Structural integrity of the product, and
3. Rehydration characteristics of the product.

The basic approach was to modify the physical, and possibly chemical, characteristics of the raw materials prior to dehydration by the application of different physical and chemical pretreatments.

Physical pretreatments included:

1. Cutting vegetables into suitable shapes and sizes to facilitate pretreatments and drying in a fluid-bed dryer.
2. Precooking, cooking, freezing and thawing of the product to modify its physical characteristics such that faster rate of drying and rehydration might be obtained.

Chemical pretreatments included:

1. Dipping raw material in calcium chloride solution to strengthen the texture of the

vegetable.

2. Dipping in glycerol and/or surfactant emulsion to modify surface tension property and hence moisture transport phenomena within vegetable pieces to accelerate drying and rehydration.

Potato was chosen for these studies since it can be dried in various forms. It was expected that information obtained from potato studies might be applicable to other vegetables with little modifications. Potato in the form of shredded hash-browns was selected because commercial dehydrated hash-browns are available, therefore, some comparison could be made.

2. LITERATURE REVIEW

2.1 Dehydrated Potato Products

The dehydration of potatoes by traditional methods has been practiced by Peruvian Indians for many centuries (Feustal, *et al.*, 1964). However, the modern potato dehydration industry got its impetus during World War I and World War II, mainly to solve military feeding problems. Today, many dehydrated potato products in the forms of granules, flakes, dice, cube, shreds and julienne strips are in commercial production. Potato chips, produced in substantial quantity may also be considered as a dehydrated product, as the process involves dehydration by heating in oil. Some experimental products such as potato "puffs", potato "nuts", sponge dehydrated potato, preformed French fries (from dehydrated potatoes), potato snacks and potato skim milk wafers have been reported (Feustal, 1975; Smith and Davis, 1968). Dehydrated riced potato for mixed cooking with rice as a main dish, have been prepared in South Korea (Kim and Yeo, 1977)

Dehydrated potato products in pieces form are used as remanufactured as well as consumer products. Dehydrated potatoes offer the manufacturer the advantage of standardizing his processing operations and maintaining uniformity in quality of products throughout the year. Meat canning industry, defence agencies, fast food restaurants and institutional food service fields are the main users of these products. Other forms such as potato granules have limited use in the remanufacturing industry.

Dehydrated hash-brown potatoes, the product used in this study, have taken an important place in the market. The dimensions of hash-browns prior to dehydration varies from 12.7 to 38.1 mm in length, 6.35 to 12.7 mm in width and from 1.6 to 3.2 mm thick or of various other shapes having at least one dimension of substantially less than 12.7 mm to achieve uniform and adequate drying (Engler and Dew, 1972). The product is prepared for consumption by reconstituting dehydrated shreds or pieces with water and browning in a skillet with a little fat. The final product consists of uneven slices or shreds of potatoes with an evenly

browned surface, crusty pieces and a moderately fine texture.

2.2 Drying Rate and Dehydration Processes for Vegetables

2.2.1 Drying Rate

The drying rate is the most important feature of dehydration. It is defined in terms of Kg of water evaporated per Kg of dry solids per hour per square meter of evaportion surface (Van Arsdel, 1963). Since it is not easy to measure or define the evaporation area of cut pieces, most often 'gross drying rate' i.e. number of Kg of water evaporated per Kg of dry solids per hour, is recorded. In the present experiment the drying rate is expressed as Kg of water removed per minute on wet basis as moisture content of raw potatoes used did not change significantly between batches. A typical drying rate curve is shown in Fig. 1.

In the beginning of drying process, at point A (Fig. 1) the product is usually at a colder temperature than its ultimate temperature and the evaporation rate will increase while the surface temperature rises to its equelibrium value. This initial unsteady state adjustment period (A to B) is so short it is ordinarily ignored in the analysis of times of drying (Geankoplis, 1983). In general, the air-drying process may be divided into two main categories :

a) constant-rate drying

b) falling-rate drying

When free water moves to the drying surface by capillary action, the drying rate is constant, i.e. the drying is in a "constant-rate period" (line BC). In this period, the water evaporates freely from the surface of the solid and drying occurs as if the pure water was being evaporated from the liquid surface. As water is evaporated, capillary forces are set up by the interfacial tension between the water and the solid. These forces provide the driving force for moving the water through the pores to the drying surface (Geankoplis, 1983). The rate of drying is independent of the solid and of the moisture content and is controlled by the air

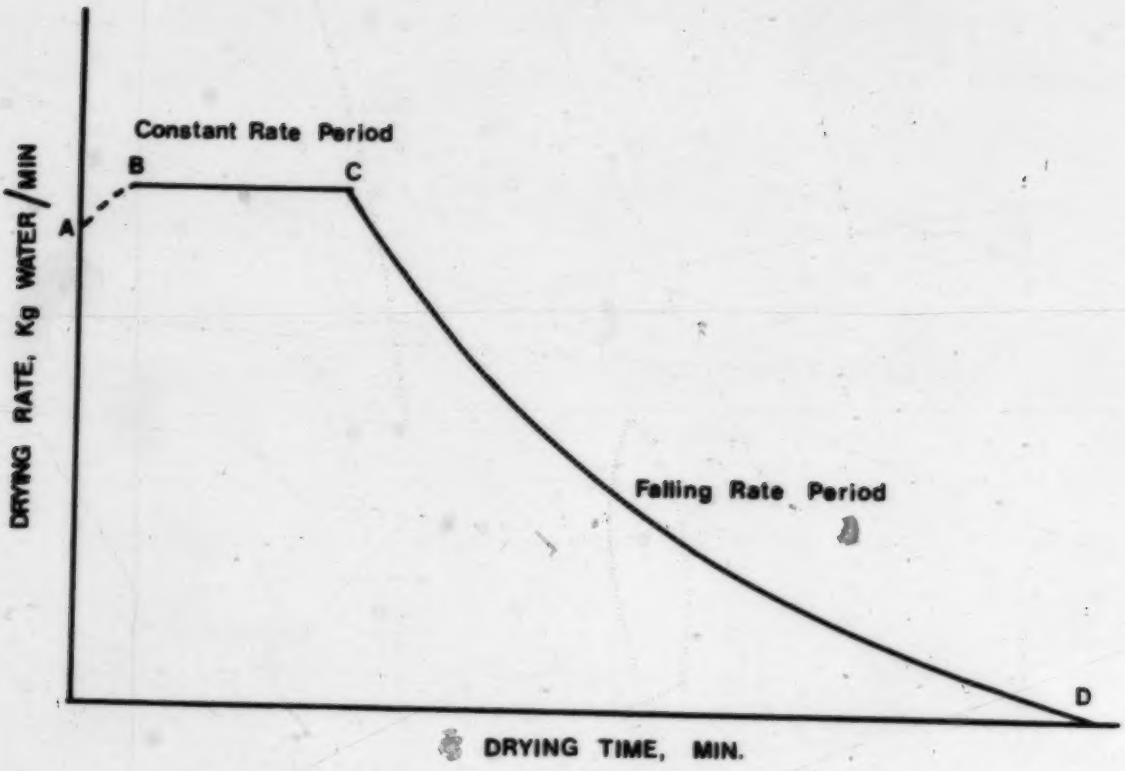


Figure 1. Typical Drying-Rate Curve of Porous Materials

temperature and velocity.

In granular solids such as sand, it produces the effect of a suction on the liquid, like in the rise of a liquid in a capillary tube which is due to a physical unbalance of forces at the interface between a liquid and gas or vapor. (Van Arsdel, 1963). Capillary flow mechanism is important, mainly for the high-moisture stage of drying. This period continues only as long as the water is supplied to the surface as fast as it is evaporated.

However, when the movement of water to the surface is restricted by diffusion, the rate of drying decreases and enters the so called "falling-rate period" (CD in Fig. 1). The drying rate continues to decrease until the product reaches its equilibrium moisture content. In other words, the end of the constant-rate period corresponds to the time when the internal migration of water to the surface can no longer support the rate of evaporation (critical period). Diffusion of liquid moisture occurs when there is a concentration difference between the depth of a solid and the surface or due to pressure and water concentration gradients. In many food materials, the movement of water in the falling-rate drying period occurs by diffusion. The diffusional transfer mechanism is also found in the late phases of drying in all cases irrespective of the mechanism which controlled the earlier phases. During the falling-rate period the rate of drying decreases continuously and prolonged drying times are required to reach a low moisture content.

Most of the foods such as potatoes do not show a constant-rate period of drying, but exhibit quite a sharp break after a slowly and steadily declining rate period (Earle, 1966). Saravacos and Charm (1962) reported that the moisture content at the transition point between the constant-rate and falling-rate period (critical moisture content, W_c) is characteristic of each material for a given set of drying conditions. They stated that most fruits and vegetables have a higher W_c due to their colloidal and hydrophilic nature which causes the water molecules to be held more tightly. As a consequence, most of the drying of these food materials takes place during the falling-rate period. They found no significant effect of blanching on the drying-rate of potatoes, but found that higher air velocity increases drying rate in the

constant-rate period with no effect on the falling-rate period as water movement to the surface is now controlled by diffusion. They reported W_c of potatoes as 3.5 g water/g of dry matter.

One of the important factors affecting the drying rate is the shrinkage of the solid as moisture is removed. Colloidal and fibrous materials such as vegetables (and other food stuffs) undergo shrinkage on drying. A layer of closely packed shrunken cells, which are sealed together, forms at the surface of foodstuffs presenting a barrier to moisture migration and is known as 'case hardening'. Slow drying rate results in shrinkage, case hardening and brown discoloration of the product. The product becomes dense making it difficult to rehydrate completely. Therefore, a faster drying rate is desirable to to minimize these problems. This is possible by modifying the physical and chemical characteristics of the materials so that the constant-rate period may be extended. The constant-rate drying has the following advantages:

1. Reduces drying time.
2. Product texture is less dense which will assist rehydration.
3. Improved product quality with respect to color and retention of flavor and nutritive value due to short residence time.
4. Improved economy as shorter drying time saves energy.

Commercially, most of the vegetables are dehydrated with a tunnel dryer or belt dryer in which the constant-rate period is very short, if at all, and most of the drying takes place in the falling-rate period. The result is usually a long drying time, 3 to 6 hours or longer, producing products with undesirable characteristics.

In the present work, a fluid-bed dryer was used for dehydration of hash-brown potatoes. Generally, fluid-bed drying permits gentle, and very efficient drying down to a very low residual moisture content due to uniform temperature distribution, and a large exchange area between solid and gas (Borgolte and Simon, 1981).

2.2.2 Dehydration Processes for Vegetables

Piece-form dehydrated vegetables are produced by several processes including hot-air and freeze drying processes. Freeze drying is an expensive process and is used for producing only a small number of dehydrated vegetables. Practically all types of cabinet, tunnel, conveyor (moving-belt), belt-trough, fludized-bed and vacuum shelf dryers have been used for producing variety of food products. Continuous conveyor type dryers are most commonly used for dehydration of vegetables. In this drying method, the vegetable pieces are conveyed on moving perforated belts where heated air is blown through the product. The drying air temperature varies from 110° to 115°C in the first stage and from 65° to 75°C in the second stage to reduce heat damage to the product. Final drying is accomplished in large bins of the material through which warm air circulates for prolonged period of time.

In general, processing steps for the production of diced dehydrated vegetables such as potato and carrots are outlined in Fig. 2.

In recent years, certain techniques have been developed using chemical additives to accelerate water removal during drying, maintain textural integrity and to improve rehydration characteristics of the dehydrated vegetable products. Heyman (1968) used acetylated monoglycerides as heat transfer media to accelerate vacuum drying of products such as ground mushroom. He claimed that the mushroom powder obtained from such a treatment retained excellent flavor and aroma and had good keeping quality. Shipman and Rahman (1974) treated prepared vegetables with 20-80% glycerol before air drying. They stated that rehydrated products retained excellent texture and acceptability. Nitrous oxide was used by Miles (1970) to preserve structure and to aid water removal in the vacuum drying of vegetables. Diced onions, carrots, celery and potatoes have been dried by this method. Blake and Pendlington (1974) added alkali metal citrates (10%) to shorten their rehydration time. Cyr (1961) discovered that breakage of dehydrated potato cubes can be reduced by treatment with 2% sodium chloride solution or to a lesser extent by treatment with solution of sodium nitrate and ammonium chloride or mixture of these solutions. Shorter rehydration time has been achieved by Cording

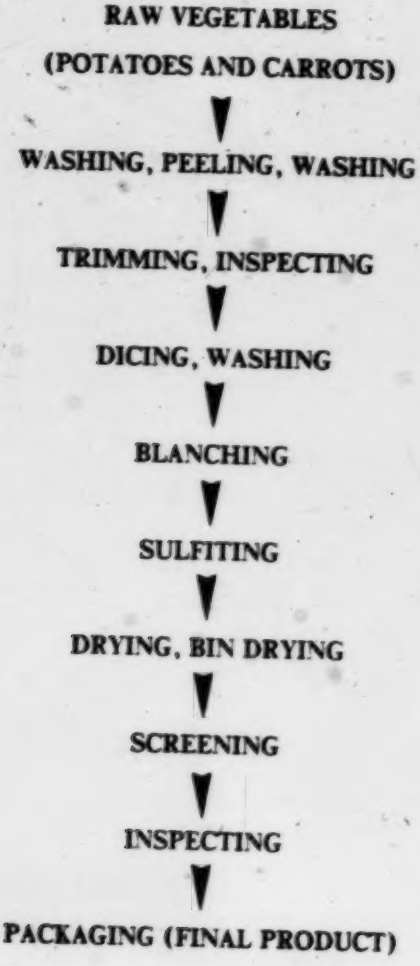


Figure 2. Flow Chart for the Dehydration of Diced Vegetables.

and Eskew (1962) for dehydrated vegetable pieces. Their process consists of placing the partially dehydrated product in a sealed chamber and producing a pressure by the application of heat. Then suddenly the pressure is released and the product is collected. They have discovered the product to be porous with shorter drying time. However, all these attempts hardly result in cheaper drying processes as most of them still rely on rather sophisticated and expensive techniques such as freeze drying, vacuum drying and lengthy air drying or combination of these methods.

2.3 Physical Treatments

2.3.1 Size and Shape of Potatoes

Size and shape of vegetable pieces have a considerable effect on rate of dehydration and rehydration characteristics of dehydrated product. Piece size also indirectly affects other quality parameters. Browning reaction is less intense in small size products as moisture content will be lower. Heat damage will be less in such products as they dry fast. On the other hand, their bulk density will be lower and loss due to breakage, handling, cutting or preparation will be higher.

Ede (1958) has found that decreasing slice thickness increases rate of drying in potato dehydration. Similar findings of the effectiveness of reducing piece thickness in accelerating dehydration, especially in the later stage of dehydration, have been reported by Simon and his Co-workers (1953). Davis and Howard (1943) have demonstrated the effect of slice thickness on the rehydration rate of dehydrated carrots.

The vegetables for dehydration may be cut into cubes, slices, strips, rings, shreds or into other types or styles depending upon the final product requirements and its end-use. Table 2 gives the U.S specifications for different types (minimum dimensions), styles of dehydrated potatoes and market use of the dehydrated products. Another style known as "random cut slices" which are prepared from small and large size potatoes, helps minimize the problems of disposal of fine pieces (Kueneman, 1975). Reeve (1971) has noticed that tissue loss from

TABLE 2

Specifications and Major Uses of Dehydrated Potatoes [1234]

Type	Product Name	Size (mm) and description	Market use
Type I	Diced	(i) 13 x 13 x 3 quarter dice or	Army rations
		(ii) 6 x 6 x 3 through	Soups, Hash-browns
		pieces of single nominal	Corned beef hash
		size (size tolerance ± 1 mm)	Meat pies
Type II	Mashed - precooked;	Pieces suitable for uniform cooking	Instant mashed
	Rapid rehydrating.		
Style A	Granules		General cooking
Style B	Flakes		Pancakes, Soups
Type III	Slices, uncooked	(i) 25 x 25 x 3 to 38 x 38 x 3	Potato salads
	(round or rectangular)	or	Casaroles, Soups
		(ii) 3 mm cross sectional cuts from	Beef stew,
		potatoes with a diameter of 64 mm or	au gratin.
		less, if potatoes are larger than	
		64 mm they shall be either cut in	
		half or quartered longitudinally	
		prior to slicing.	

[1]U.S. Army and Federal specifications, 1979. [2]U.S. Dept of Agr., 1982. [3]Wiliard, 1957. [4]Lazar and Rasmussen, 1964.

cutting and slicing increases as the size of slices decreases. The smaller the pieces or the thinner the slices, the greater is the loss from cutting operations. Clean and sharp cuts reduce these losses due to less additional tearing of cells.

Therefore, in preparing vegetables for dehydration, their size and shape should:

- satisfy market and consumer requirements
- facilitate pretreatments such as precooking, cooking, sulfiting, dipping etc.,
- be suitable for dehydration in an efficient type of dryer, and
- take into account bulk density breakage in handling, and packaging needs of dehydrated products.

2.3.2 Pre-cooking and Cooking

In the normal dehydration process, the potatoes after peeling, cutting and washing are generally blanched or cooked in steam or in water. To adequately cook tuber pieces cooking time may vary from two to twelve minutes depending upon factors such as size of pieces, temperature of cooking, and variety and maturity of potatoes. Steam is prefered to water as a cooking medium, as boiling in water results in leaching i.e. loss of soluble solids such as sugars, proteins, ascorbic acid, soluble starch and metal ions.

The cooking process is characterized by such physico-chemical changes as gelatinization of starch, solubilization of some of pectic substances, increased digestibility of cellulose, coagulation of most of protein and some caramelization of sugars (Sweetman, 1933). Numerous papers have described textural quality of potatoes as related to cooking. Two important components of potatoes, starch and pectic substances, are affected during precooking and cooking of tuber slices.

Starch makes up about 65 to 80% of the total dry weight of the potato tuber and calorically is the most important nutritional component. Table 3 gives the proximate analysis of white potatoes. Starch in the form of microscopic granules is present in the leucoplasts of the cells of the parenchyma tissue. They are ellipsoidal in shape, with an average size of about

Table 3

Proximate Analysis of Potatoes

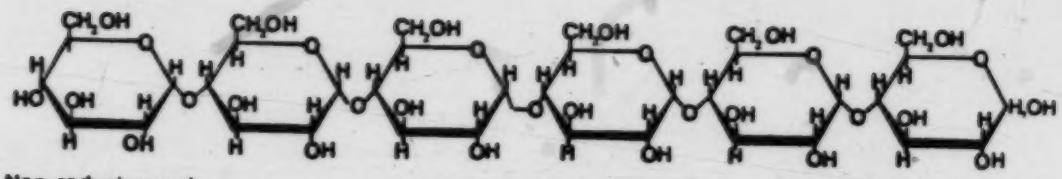
	Average (%)
Water	77.5
Total Solids	22.5
Protein	2.0
Fat	0.1
Carbohydrate	
Total	19.4
Crude fiber	0.6
Ash	1.0

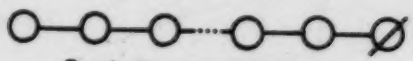
From : Tulburt, *et al., 1975.*

100 x 10 microns. Each starch granule is reported to be surrounded by a membrane (Hall and Sayre, 1970). Chad *et al.* (1971) observed that this membrane disintegrates when potatoes are stored at 40°F (4.5°C), leading to a reduction in starch content and an accumulation of sugars.Reeve (1967b) observed a slight increase in the size of starch granules with increased storage temperature. At higher temperatures smaller grains are digested more rapidly than larger ones. Generally, it is a common practice in the processing industry to "recondition" the potatoes which have been previously stored at 40°F (4.5°C) or lower, at a temperature of around 75°F (24°C) to reduce the amounts of the accumulated sugars and improve the processing qualities.

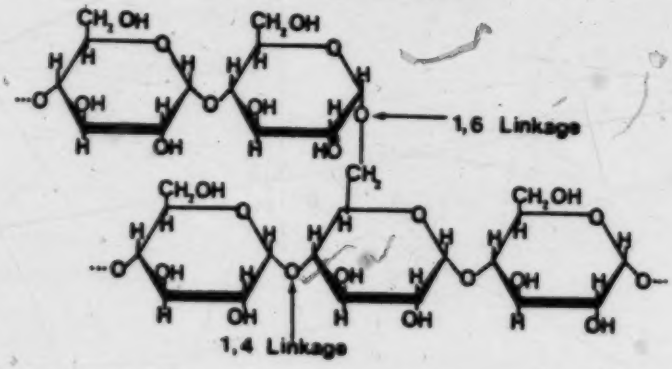
Starch is a polysaccharide which consists of two main components (Fig. 3a ,3b) amylose, a polymer of α-1,4 linked glucose residues with little branching and amylopectin, a highly branched, chained glucose polymer in which, in addition to α-1,4 linkage, the side chains are attached through α-1,6 linkages.

The starch content is considered to be important factor in influencing the potato texture. Softening of a potato during cooking is associated with cell separation. The relative sogginess or mealiness, i.e the extent of cell separation in cooked potatoes, appears to be related to the starch content. On the other hand specific gravity and mealiness is correlated with cell size and the size of its starch grains, which are also positively correlated with tuber size (Sterling, 1966). Mealiness is a desirable textural quality of rehydrated potato products. Hoff (1972a) pointed out other factors, e.g. amylose/amylopectin ratio of the starch, the extent of retrogradation, the effects of specific gravity and total solids, cell size, cell surface, contents of Ca^{2+} and organic acids and age and storage time of the tuber, which would influence texture of cooked potatoes. Reeve (1954a) showed with his microscopic observations that cell separation is accompanied by "rounding off" of the cells, the result of swelling of gelatinized starch. The "Swelling pressure" theory is supported by Sterling and Bettelheim (1955) and Whittenberger (1951) which asserts that a high level of starch in potato cells leads to the absorption of water during cooking, swelling and "rounding off" of the cells and hence cell separation. However,

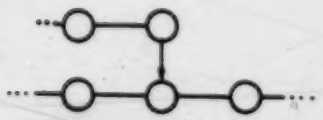




(a) Symbolic representation of an amylose chain

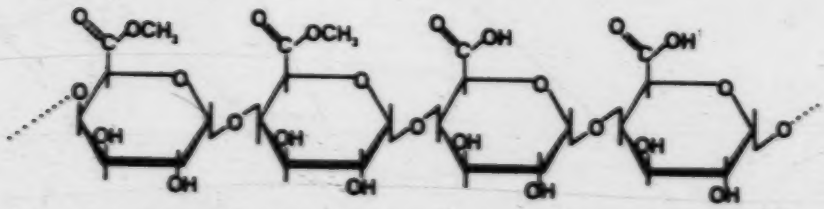


Branch point in amylopectin or glycogen



(b) Symbolic representation of a branch point in amylopectin or glycogen

Chemical Structure of the Amylose (a) and Amylopectin (b) Chains and their Symbolic Representations. (French 1979)



(c) Galacturonic acid and methyl galacturonate units of pectin (Rodge & Osman, 1975)

Figure 3. Basic Chemical Structure Components and Pectic Substances.

other workers suggest that the "swelling pressure" theory is inadequate to explain the cause of mealiness. Bretzloff (1970) observed that the size of the cells in an intact sample of potato tissue did not change when heated on a microscopic stage and Hoff (1972) noted no increase in volume when starch was heated to bring about starch gelatinization in a closed system. Warren and Woodman (1974) suggested that mealiness is the subjective perception of the flow characteristics (viscosity) of cooked tissue and this aspect of texture is contributed primarily by the solids content of the tuber. Linehan and Hughes (1969) pointed out that the firming effect of texture is due to diffused amylose which might act as a cement between potato tuber cells by formation of hydrogen bonds with polysaccharides of cell wall. However, this would not be justified as no hydrogen bonding between starch and cell wall polysaccharides was observed by Keijbets *et al.* (1976). In fact, it is a general practice to wash out extra surface or diffused starch after peeling, cutting and cooking, as it may hinder the drying process.

Reeve (1954a) demonstrated that starch gelatinization, cell separation and cell rupturing are interdependent changes that occur when potatoes are cooked. The precooking and cooling caused hydration, swelling and gelatinization of starch grains. Gelation of the granule is intiated by the beginning of the solubilization of amylose, the straight chain fraction of the starch. The granule hydrates and the branched amylopectin begins to swell, its crystalline structure is then lost and a gel is formed. Hoover and Hadziyev (1981) reported that potato tuber starch has a gelatinization temperature range of 56.8 to 58.5°C, as indicated by loss of birefringence. Upon cooking of potatoes at higher temperatures between 87.7°C, to 100°C, the starch granules are rapidly gelled and some of the soluble amylose diffuses out of the gel (Reeve, 1954b). Processing at 65°C and then cooking at 100°C has been shown to decrease dissolved starch content (Potter *et al.*, 1959). The decrease was more noticeable as the preheating time was increased, suggesting that at preheating temperature starch retrogrades (realignment and association of starch molecules by hydrogen bonding into organized insoluble aggregates). This effect is even more pronounced when precooking was followed by a cooling step (Potter, 1954; Reeve, 1954a; Harrington *et al.*, 1959). Precooking has also been reported in

the firming effect of potato tissue. Reeve (1954a), Cording and Willard (1957) and Moledina *et al.* (1978) found that precooking of tuber slices and subsequent steam-cooking increased the firmness of unmashed potato tissue in granule production. Moledina *et al.* (1978) suggested that the firming effect of precooking of potato slices at 70°C for 20 minutes and subsequent steam cooking was due to lower solubilization of pectic substances.

Pectic substances occur as constituents of plant cell-wall and in the middle lamella. They may be divided into different forms such as protopectin, pectinic acids, pectin and pectic acid. The American chemical society has provided the following definitions for pectic substances (Kertesz, 1951) :

> Pectic substances. "Pectic substances" is a group designation for those complex colloidal carbohydrate derivatives which occur in, or are prepared from, plants and contain a large proportion of anhydrogalacturonic acid units which are thought to exist in a chain like combinations. The carboxyl groups of polygalacturonic acids may be partially esterified by methyl groups and partially or completely neutralized by one or more bases.
>
> Protopectin. The term protopectin is applied to the water soluble parent pectin substance which occurs in plants and which, upon restricted hydrolysis, yields pectinic acids.
>
> Pectinic acids. These are colloidal polygalacturonic acids containing more than a negligible proportion of methyl ester groups. The salts of pectinic acids are either normal or acid pectinates.
>
> Pectin. The general term pectin (or pectins) designates those water soluble pectinic acids of varying methyl ester content and degree of neutralization which are capable of forming gels with sugar under suitable conditions.
>
> Pectic acids. These pectic substances are composed of mostly colloidal polygalacturonic acids and are essentially free from methyl ester groups. The salts of pectic acids are either normal or acid pectates.

A linear chain of anhydro-D-galacturonic acid units connected by α-(1→4) linkages is the basic structure of pectic substances (Fig 3c), in which carboxyl groups are more or less methylated. Petic substances constitute on the average about one per cent of the dry weight of the potato. Potter and McComb (1957) reported that the content of pectic substances in potatoes, based on the anhydrouronide content, ranges from 0.7 to 1.5 per cent of dry weight of the potatoes.

In processed potatoes, there is a loss of cellular cohesion of tissue, suggesting a relationship between cohesion and solubilization of pectic substances. It appears that precooking renders the pectic substances in the middle lamella more resistant to further thermal degradation, thus decreasing the loss of intracellular cohesion and the rarefaction of cell wall brought about by subsequent cooking.

There have been different views on the firming effect in potato tissue. Bartolome and Hoff *et al.* (1972) and Hoff (1973) reported that the beneficial firming effect of precooking is due to the de-esterification of the cell wall pectin by potato tuber pectin methylesterase (PME). Firming occurs by metal bridge formation between the freed carboxyl groups and Ca^{2+} and Mg^{2+} diffused from the cell interior. However, recent researchers, Moledina *et al.* (1981) presented the different view that the firming effect is due to Ca- release from gelatinized starch during precooking at 70°C for 20 minutes and stabilization of Ca^{2+} bridges with freed COO^- groups of the cell wall pectin during cooling and they de-emphasized the role of PME in causing firming.

Substances other than pectic (lignins, suberins, catins and protein) may be present in the middle lamella and within the cellulosic matrix. These may influence the degree of cell separation on processing (Reeve, 1954a). The cellulosic matrix is composed of microfibrils in various degree of orientation and these structural conditions may influence elasticity and strength in plant cell walls.

One of the other important interrelated factors in potato texture is the sloughing or the disintegration of tuber tissue on cooking. This is most common with potatoes of high solids

content. The integrity of potato slices is important in dehydration process. Warren *et al.* (1975) stated that high levels of polyuronides and phytate and low levels of polyvalent metal ions in the cell wall favor breakdown or cell sloughing when potatoes are cooked. Wager (1963) suggested that phytin leads to softening after cooking by acting as a calcium precipitant in older potatoes. The treatment of precooking and cooking of potato slices in solution containing calcium ions, is usually done for strengthening the potato tissue to check sloughing.

Overcooking of potato pieces causes another effect known as "Popcorn", and is characterized by porous opaque areas in otherwise translucent dehydrated pieces (Campbell *et al.*, 1945; Reeve, 1954c). Reeve (1954c) noticed many minute air pockets in these areas suggesting that the opaque porosity might be resulted from a partial cell separation and expansion of gases when the tissues were dried in hot air.

2.3.3 Low Temperature Treatment

Low temperatures, both above and below freezing point, are known to modify the texture of starch-rich and other vegetable products through retrogradation of starch (Olson and Harrington, 1955). The phenomenon of retrogradation, or the decrease in soluble starch, is considered due to an association of the starch molecules, probably by hydrogen bonding, either directly or through molecules of water, bridging between active sites of the starch molecules (Boyle, 1975).

Ooraikul (1977) produced an improved quality of potato granules by including freezing and thawing steps in the manufacturing process. This technique also accelerated the drying process, suggesting that on freezing, the intercellular liquid becomes more concentrated when pure ice crystals form in the intercellular spaces of the tuber cells. This results in the movement of water from inside of the cells to the outside through the cell walls by osmosis. Moisture, then remains outside the cells which on thawing accelerates the drying. The freezing and thawing steps were also reported to toughen the potato cells so that they can withstand mild mechanical force during drying. It is postulated that modification of the cell wall porosity by

these pretreatments can result in faster drying in a stream of hot air.

Low temperature treatments also affect the rehydration characteristics of dried products. Pretreatments of heating, freezing, and thawing alter the moisture reabsorbing capacity of the starch gels (Reeve, 1954c). This influences the texture of the reconstituted products and the degree of porosity in dried products. Cooked, frozen, thawed and dehydrated potato cubes and slices have porous structure. Fineness of porosity varies according to the freezing and thawing treatments and also with precooking methods. Longree (1950) demonstrated a relationship between freezing and properties of gelled starch in cooked and frozen potatoes. He described the "cottoniness" of texture as an extreme form of mealiness associated with the more shrunken cells in which the gelled starch has lost some of its moisture reabsorbing capacity.

In the manufacture of "sponge dehydrated potatoes", freezing and thawing of potato slices resulted in firming of structure and maintenance of physical properties throughout subsequent dehydration process. The responsible action appears to be an egress of water from cell constituents into intercellular ice formations as the product passes slowly through a temperature range of approximately 0 to 20°C.

2.4 Chemical Treatment

2.4.1 Calcium Treatment

In order to produce dehydrated potatoes of desired size and thickness, it is important not only to maintain the integrity of potato piece during pretreatments and drying, but also after reconstitution especially for use in manufacturing products such as salads, soups and stews. Addition of calcuium to cooking water or its presence during a precook soaking treatment has the effect of toughening cooked potato tissue and in reducing sloughing. The strengthening of cell structure is the result of interaction of calcium with pectic substances of the cell wall and formation of calcium bridges. Earlier researchers used calcium salt to produce

dehydrarted potatoes of desired thickness which did not slough or became mushy during rehydration and cooking (Simon *et al.*, 1953). The application of Ca^{2+} salt in thinner pieces (as in this experiment) is of significant importance, as these sizes of pieces are more prone to breakage. On the other hand, the thinner pieces generally dehydrate more rapidly and rehydrate more quickly and more completely than the thicker pieces.

Recent work in this department has proven that calcium strengthens cell wall and middle lamella of potato tissue when added during the precooking step of the potato granule production (Haydar *et al.*, 1980; Moledina *et al.*, 1981). The experiment of Hayder *et al.* (1980) showed that solubilization of pectin substances in isolated potato cell walls was suppressed during precooking by Ca^{2+} but not by Mg^{2+} and was highest when Ca^{2+} equivalents stoichiometrically corresponded to or exceeded pectin free carboxyl groups.

It is also known that calcium but not magnesium retards pectin solubilization (Keijbets *et al.*, 1976; Moledina *et al.*, 1981). Potato starch proves to be a good source of Ca^{2+} after starch gelatinization. Ca^{2+} diffuses to cell walls and forms Ca^{2+} bridges with pectin free COO^- groups. Cooling after precooking reduces the Ca-pectate solubility allowing the stabilization of these bridges. Ca-bridges would render the pectin more resistant to further solubilization during cooking. This would then increase and optimize potato tissue firming or potato cell cohesion, thus preventing sloughing during cooking (Hadziyev and Steel, 1979).

Keijbets *et al.* (1976) reported that during boiling, calcium ions had the ability to stabilize the pectic galacturonan in potato cell-wall, even when it was progressively depolymerized. They also pointed out that pectin was degraded by a β-elimination reaction which takes place adjacent to an esterified carboxylic acid on the pectin.

The degree of esterification (D.E.) of the pectin in potatoes plays an important role on the cooking stability of the pectin (Johnson and Kinsella, 1981). On cooking this elimination reaction takes place on the pectin leading to chain scission. These researchers suggested that fragments of pectin sufficiently small to be mobile are produced and may migrate to the outer surface and be lost. Divalent calcium ions present either in the potato or in the cooking water

are able to complex with two portions of the chain in the structure and would require further degradation before loss occurs.

Reeve (1967a) has stated that calcium decreases the swelling of gelled starch and increases the firmness of the gel. The presence of $CaCl_2$ in dehydrated potatoes renders the products less susceptible to non-enzymatic browning during storage (Simon *et al.*, 1955). The exact mechanism how Ca^{2+} retards browning is still not known. It is beleived that calcium may be acting in some manner to block the amino group, whereby the latter is restrained from entering into the browning reaction.

The use of calcium in the present studies is to improve the textural integrity of the product, thus reducing its density and excessive physical damage, and possibly assisting the rehydration as well.

2.5 Surfactant Treatment

In the production of potato granules, the use of monoglycerides have been ascribed in suppressing the stickiness of gelled starch by binding with starch gel (Ooraikul and Hadziyev, 1974). A blend of monoglycerides, Myvatex® (a mixture of glycerol monostearate and propylene glycol monostearate) is found superior to the use of a single monoglyceride.

Bourne *et al.* (1960) demonstrated that monoglycerides complex readily with solubilized starch, and suggested that the complex could be a host-guest, non stoichiometric clathrate compound in which the fatty acid chain is located within the amylose helix. Hoover and Hadziyev (1981) used X-ray diffraction analysis to show that such complexes are true clathrate (inclusion) compounds and the cathrate stability is a function of monoglyceride chain length. Ooraikul and Hadziyev (1974) also found that surfactants reduce the viscosity of pectic solutions. In their studies , they used a mixture of glycerol-and propylene glycol monostearates at the concentration level of 0.1% in a model system using slow set pectin solutions.

Heyman (1968) used acetylated monoglycerides as heat transfer media to accelerate drying of products such as ground mushroom in a vacuum dryer. He claimed that the

mushroom powder obtained retained excellent flavor and aroma and had good keeping qualities.

Surfactant was used in the present experiment in an attempt to improve the dehydration /rehydration characteristics of the product.

2.5.1 Glycerol Treatment

Glycerol is used in many manufactured foods to improve their textural properties. It is added to achieve one or more functions such as improvement of rehydration characteristics, crystallization retardation, moisture retention and improvement of stability on aging.

In the production of dehydrated compressed foods, Brockmann (1969) has determined that the inclusion of a small amount of a glycerol during dehydration will allow a marked improvement in quality of rehydration characteristics.

Shipman and Rahman (1974) treated vegetable products with 20-80% glycerol prior to air drying. They stated that rehydrated products retained excellent texture and acceptability.

Soaking of shredded potatoes in glycerol alone and in combination with other treatments prior to drying has been tried in the present studies to improve rehydration characteristics and to reduce breakage of the product.

3. EXPERIMENTAL

3.1 Materials

3.1.1 Potatoes

The potatoes used for processing were cultivar Netted Gem (Russet Burbank) supplied by I & S Produce Ltd., Edmonton, AB, with S. G. of 1.098 (corresponding to a dry matter content of 23.7%). Raw potatoes were stored at 4°C and were reconditioned at room temperature prior to processing.

3.1.2 Chemicals

i. Calcium chloride, dehydrated, granular, food grade. J. T. Baker, Chemical Co., Phillipsburg, NJ

ii. Glycerol, white, USP, FCC. Fisher Scientific Co., Fairlawn, NJ.

iii. Sodium acid pyrophosphate (Taterfose), food grade, obtained from Stauffer Chemical Co., Westport, CT.

iv. Sodium meta-bisulfite, reagent grade. J.T. Baker Chemical Co., NJ.

v. Surfactant, Myvatexe 3-50 (Type C-18), distilled monoglycerides, a blend of propylene glycol monostearate and glycol monostearate, obtained from Eastman Kodak, Kingsport, TE.

All the other chemicals used in this study were of reagent grade and were supplied by Fisher Scientific Co.

3.1.3 Equipment

1. Potato hydrometer, Potato Chip Institute International, Cleveland, OH.
2. Hobart vegetable peeler. The Hobart Mfg. Co. Ltd., Don Miller, Ont.
3. Hobart grater, 8 mm, Hobart Mfg. Co. Ltd., Edmonton, AB.

4. Manesty Petrie Fluid-bed dryer, Model MP 1OE. Manesty Machines Ltd., Speke, Liverpool, UK.
5. Speedomax temperature recorder, Electronik 112. Honeywell, Fort Washington, PA.
6. Canadian standard sieve series. The W.S Tyler Co. of Canada Ltd., St. Catherines, Ont.
7. Vacuum oven, Model No. 19. GCH Corp., Precision Scientific Group, Chicago, IL.
8. Blast freezer (walk-in). Bally Refrigertion of Canada Ltd., Brockville, Ont.
9. Atomic absorption spectrophotometer, Model SP2900. Pye Unicorn Ltd., Cambridge, UK.
10. Instron universal testing instrument, Model 1132., with 50 Kg compression load cell. Instron Corp., 2500 Washington St., Canton, MD.
11. Kramer standard shear-compression cell, Model CSI. Food Technology Corp., 11425 Isaac Newton Square, Fourth Reston, VA.
12. Hunterlab Colorimater, Model D25L-2. Hunter Associates Laboratory Inc., Fairfax, VA.
13. Centrifuge, IEC, Model S2K, International Equipment Co., Needham, Heights, MA.

3.2 Methods

3.2.1 Specific Gravity

Potatoes were cleaned with a dry cloth and their S.G. was measured directly with the standard Hydrometer (Potato Chip Institute International Hydrometer) using 3.63 Kg (8 lb) of potatoes in water.

3.2.2 Preparation and General Processing Procedure

The general procedure devised for the preparation of hash-brown potatoes is shown in Fig. 4.

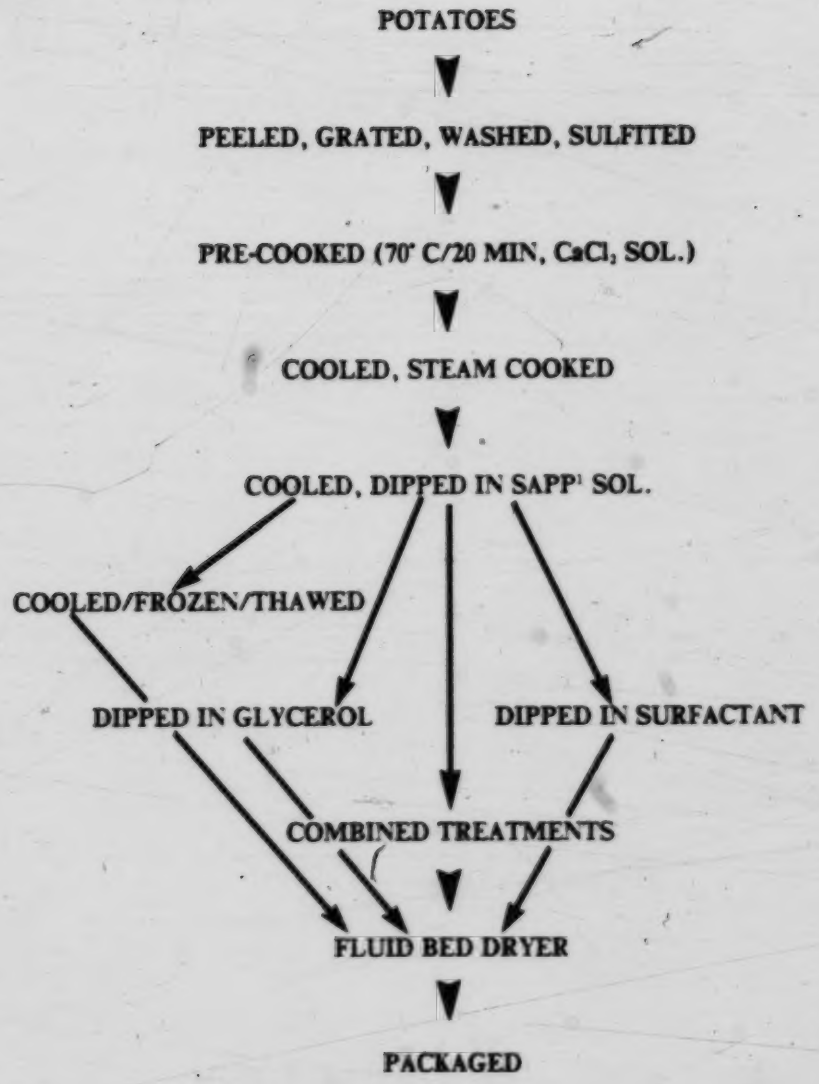


Figure 4. Flow Chart for Dehydrated Hash-brown Potatoes.

[1] Sodium acid pyrophosphate.

Preparation

The potatoes were abrasion peeled in the Hobart peeler. Eyes and dark spots were removed with stainless steel knives. The peeled potatoes were kept immersed in water to avoid enzymatic browning and then immediatly shredded with a 8 mm Hobart grater. The grated potatoes were then throughly washed to remove surface starch and were soaked in 0.5% sodium meta-bisulfite solution for a few minutes to check enzymatic and non-enzymatic browning during drying.

The potatoes were precooked (70°C/20 min) in $CaCl_2$ solution at three concentrations (0, 200, 400 ppm as Ca^{2+}) and cooled to room temperature in $CaCl_2$ solution of the same concentration before being cooked for 0, 10 or 20 minutes. The potatoes were then cooled in 0.2% sodium acid pyrophosphate to inhibit after-cooking blackening of the potatoes. This pretreated material was drained, centrifuged (1,000 rpm for 5 min), weighed and dried in a fluid-bed dryer.

After evaluating the products with respect to drying and rehydration characteristics, the best combination of $CaCl_2$ concentration and steam cooking time (200 ppm as Ca^{2+}, 10 min cooking) was selected. The potatoes treated up to this point were subjected to further pretreatments as follows:

I. Cooling

The product was cooled to 4°C in a walk-in cooler before drying.

II. Freezing and thawing

The prepared potatoes were frozen to -22°C in a blast freezer and partially thawed to about 0°C before drying.

III. Glycerol treatment

The prepared potatoes were soaked in glycerol solution of 1, 5, 10% concentration for 30 min to six hours, then drained and centrifuged before drying.

IV. Surfactant Treatment

Emulsions of 0.1, 0.25 and 0.5% surfactant, (Myvatex® 3-50), distilled monoglycerides (at least 90%)), were prepared by blending the surfactant in lukewarm water in a waring blender and made up to the required concentrations with cold water. The cooled potato samples were immersed in an emulsion for 30 min before drying.

V. Combination of glycerol and surfactant

After the best surfactant and glycerol concentrations had been selected based on their effects on the drying, rehydration and breakage of the product, an emulsion of Myvatex® and solution of glycerol were mixed together.

The cooked potato samples were then soaked in the Myvatex®/glycerol emulsion for 30 min before drying.

3.2.3 Drying

The potato samples after cooking and pretreatments were dried in a batch type Manesty Petrie fluid-bed dryer, same as described by Ooraikul (1973) in his experiments with potato granules, with some additional modifications.

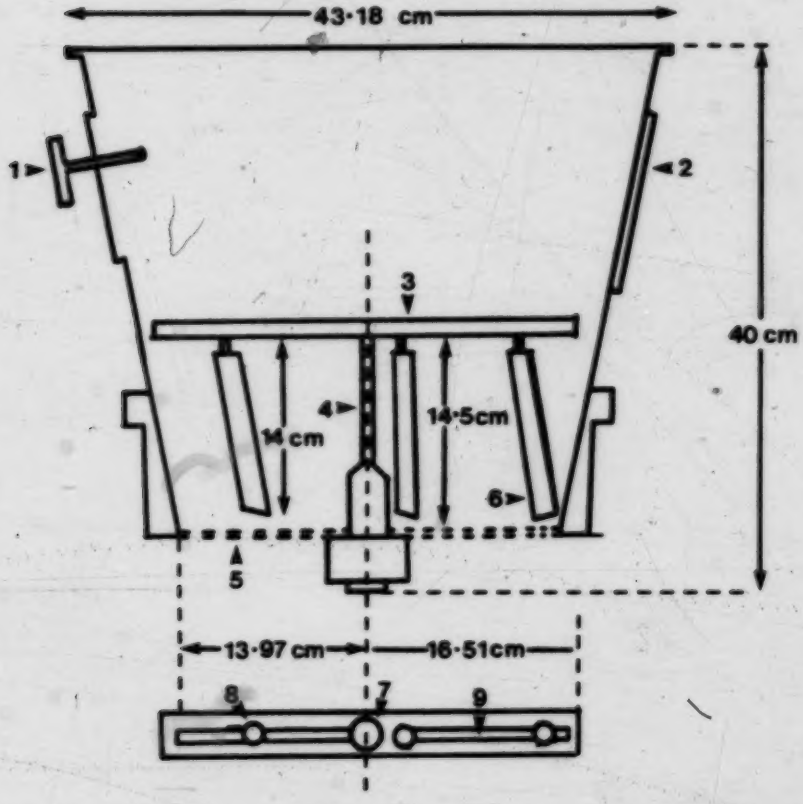
The drying setup is shown in Fig. 5. The air enters through the aluminium airflow pipe (1) to be electrically heated in the heating chamber at the back of the cabinet. The heated air is drawn through the drying bowl (4) with perforated bottom (120 mesh) by a one H.P fan motor (3), thus fluidizing the product in the collecting bag (5). The nylon collecting bag was held tightly around the drying bowl with a snap-on belt. The orifice slide (2) with known diameter (12.065 cm) was inserted 1.27 meter from the opening of the pipe. The airflow was determined by measuring the differences in air pressures up and down stream from the orifice, using a glass manometer (9). The dryer was slightly modified by lining its walls with 5 cm thick styrofoam to reduce heat loss and maximize the drying efficiency.

A rotary stirrer made of aluminum was designed to achieve the stirring of particulate product such as shreds and pieces during drying (Fig. 6). A vertical drive-shaft (14.5 cm long)

COLOURED PICTURES
Images en couleur

1. Air-Flow Pipe
2. Orifice Slide
3. Fan Motor
4. Fluidizing Bowl
5. Collecting Bag
6. Stirrer Motor
7. Ratiotrol
8. Speedomax Recorder
9. Manometer

Figure 5. Manesty Petrie Fluid Bed Dryer.



1 Thermometer
2 Observation Window
3 Aluminum Stirrer (30·5 x 2·5 x 1 cm)
4 Drive Shaft (2 cm dia.)
5 Porous Plate
6 Aluminum Stirrer Blades (14 x 2 x 1 cm)
7 Drive Shaft Screw
8 Stirrer Blade Screw
9 Blade Adjustment Slot

Figure 6. Fluidizing Bowl fitted with the Stirrer.

in the centre of fluid-bed was fitted with stirrer set-up consisting of aluminum arm and three adjustable aluminum blades.

Dry bulb and wet bulb temperatures of fresh air entering the system and temperatures of drying air and moist air leaving the bed were recorded automatically on the speedomax temperature recorder (8, Fig. 5). The difference in air pressure flowing through the orifice (measured by a manometer), was used in the calculation of mass-flow rate of the air.

The drying rates were calculated at various steps of the drying process from the air flow and temperature measurements and the rate of loss of moisture from the bed.

The air velocity was calculated using the equation adapted from A.S.M.E. Research Committee on Fluid Meters (Boucher and George, 1963) :

$$\dot{m} = CYA_2\sqrt{\frac{2g\ (p_1 - p_2)\rho}{1 - \beta^4}}$$

$$= KYA_2\sqrt{2g\ (p_1 - p_2)\rho}$$

Where :

$\dot{m}$ = mass flow rate of air, $Kg.s^{-1}$;

C = coefficient of discharge, dimensionless ;

Y = expansion factor, dimensionless ;

A_2 = cross-sectional area of throat, m^2 ;

g = gravitational constant, 9.81 $m.s^{-2}$;

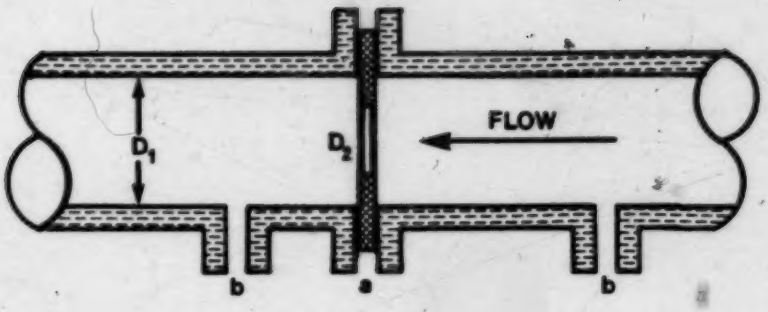
p_1, p_2 = pressure at upstream and downstream , static pressure taps, respectively, Pa ;

ρ = density at upstream pressure and temperature, $Kg.m^{-3}$;

β = ratio of throat diameter to pipe diameter, dimensionless ;

K = $C/\sqrt{1 - \beta^4}$, dimensionless.

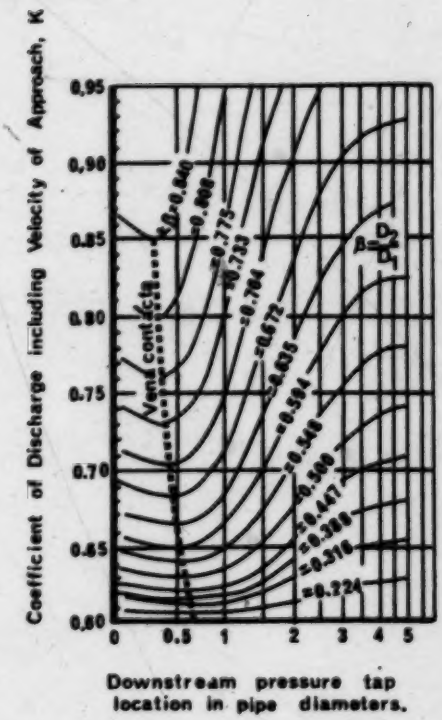
K was determined by using Fig. 7b adapted from Spitzglass (1922).



a. Pipe-line Orifice

b. Radius Taps

Square-edged or Sharp-edged Orifice



Coefficient of Discharge for Square-edged Circular Orifice.

(Spitzglass 1922)

Figure 7. Determination of Coefficient of Discharge.

Y was calculated from the following equation :

$$Y = 1 - [(1 - r)\ k](0.41 - 0.35\beta^4)$$

Where :

r = ratio of downstream to upstream static pressure, p_2 / p_1 ;

k = ratio of specfic heats, c_p / c_v.

c_p = specific heat at constant pressure ;

c_v = specific heat at constant volume.

The value of r was interpolated as follows :

$$p_2 / p_1 = (P_{atm} - \Delta P) / P_{atm}$$

$$\Delta P = 2h_w \rho_w g$$

where :

h_w = differential pressures, in water, m ;

ρ_w = density of water, $Kg.m^{-3}$;

ΔP = difference between upstream and downstream static pressures, Pa.

It was found that the minimum value of Y involved in the subsequent calculation was only 0.999, so the term was omitted.

The absolute humidity of the air entering the dryer is determined from the inlet wet and dry bulb temperatures and also with the temperature of the air below the bed which determines the moisture of the air at this point.

The absolute humidity of the air, ΔH (Kg moisture/Kg dry air) is calculated by using the psychrometric chart shown in figure 8.

The drying rate of the bed, the Kg of water removed per sec (W), is then given by the equation :

$$W = \Delta H.\dot{m}$$

Where m is the mass flow rate of the air, (Kg. Sec $^{-1}$)

3.2.4 Packaging

After drying, the product was cooled to room temperature before packing into polyethylene bags. The dried potatoes were stored at room temperature for further evaluation.

3.2.5 Product Evaluation and Characteristics

3.2.5.1 Breakage of the Product

Standard sieve #8 mesh was used to measure the extend of breakage of the product. The pieces retained on the sieve were packaged as product and the percentage of breakage was calculated from the ratio of particles passing through #8 mesh and of total weight.

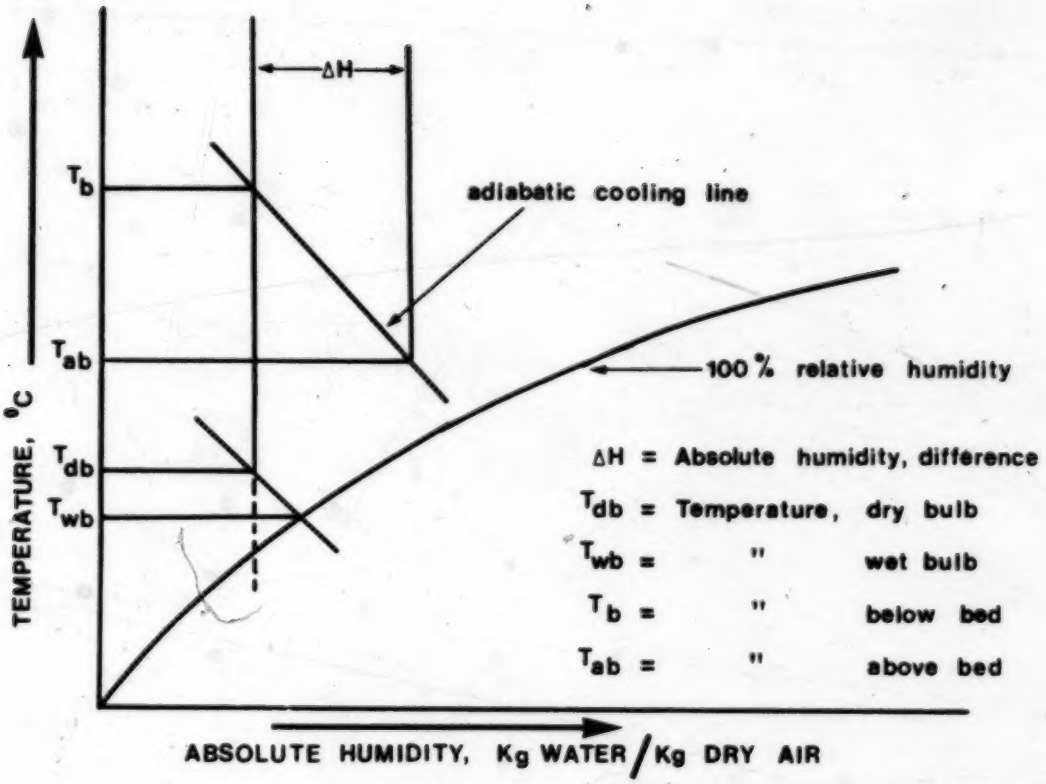


Figure 8. Psychrometric Chart with Typical Drying Rate Calculation.

3.2.5.2 Bulk Density

The bulk density of the product was measured by filling the product into a 500 ml graduated cylinder up to the 500 mark while gently tapping the cylinder until there was no further packing of the product. The product was then weighed and the bulk density was calculated in g/cm^3.

3.2.5.3 Moisture Content

The following method was used for the determination of moisture content of dehydrated product as described in U.S. Dept. of Agriculature Specifications (1982):

Approx 100 g of well mixed sample (dehydrated hash-brown potatoes) was ground for one minute in a clean dry waring blender. The ground material was placed in a small dry, tightly closed container for one-half hour before passing over a 20 mesh screen nesting on a 40 mesh screen. The portion which passed through the 20 mesh but not the 40 mesh screen was analysed for moisture content. Approx. 2 g of the material was weighed into dry aluminum dishes. The dishes, with cocked lids, were placed in a vacuum oven and dried for 6 hours at 70°C under pressure of not more than 100 mm of mercury. A slow current of air (approx. two bubbles per second), dried by passing through concentrated sulfuric acid, was admitted to the oven. The dishes were removed and were allowed to cool in a desiccator before weighing and the percentage of moisture calculated.

3.2.5.4 Rehydration Method

The following procedure, as described by Von Loesecke (1955), with modifications, was adapted for rehydration of the dry product :

Ten grams of dry product was added to the 200 ml of boiling water in a 500 ml beaker, covered with a watch glass and boiled for a set period of time on a hot plate. After boiling, the material was poured into a 75 mm Buchner funnel. A gentle suction was applied and water was drained with careful stirring for half to one minute or until the drip from the funnel had stopped. Immediately, the drained material was weighed and the water

absorption of the product, rehydration ratio, coefficient of rehydration and percentage of water in the rehydrated sample was calculated.

The following equations were used in the calculation of rehydration characteristics (Von Loesecke, 1955):

I. Dehydration ratio (D.R) $= W_o / W_d$

II. Rehydration ratio (R.R) $= W_r / W_d$

III. Coefficient of rehydration (C.R) $= \dfrac{W_r\ (100 - A)}{(W_d - W_m)}$

IV. Per cent of water in rehydrated sample (W_{rm}) $= \dfrac{W_r - (W_d - W_m)}{W_r} \times 100$

Where :

W_o = weight of prepared sample before drying ;

W_d = weight of dehydrated sample ;

W_r = weight of rehydrated sample ;

W_m = weight of moisture in dehydrated sample ;

A = % moisture (wet basis) in material before dehydration.

3.2.5.5 Texture Measurement

Instron Universal Testing Instrument with 50 Kg load cell was used to evaluate texture characteristics. The instrument was calibrated before use, as per manual instructions.

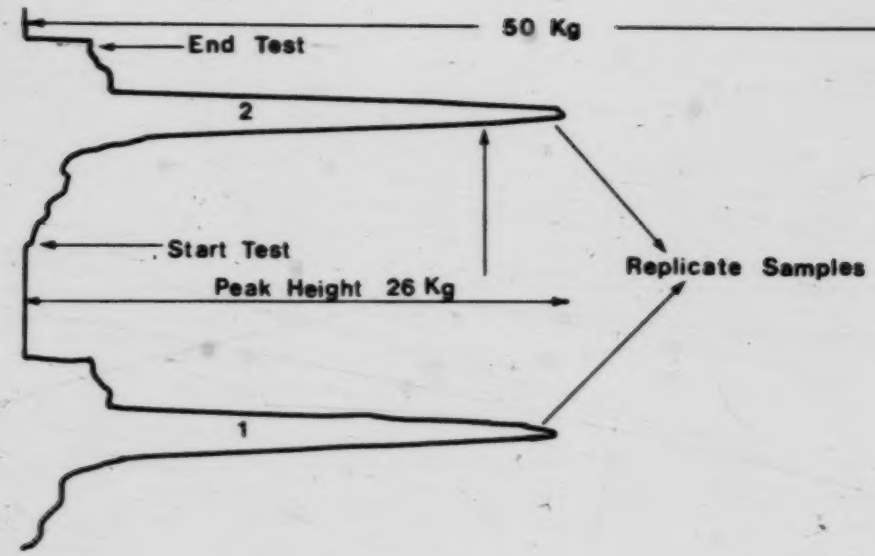
A standard compression cell was selected for testing of the product. In this test first the dried hash-brown potatoes were rehydrated in boiling water for 30 minutes, drained, centrifuged and then a known quantity (25g) of this reconstituted product was used in the test. Peak height which corresponds to the force required in crushing and extrusion of the product through the Kramer cell (slotted plate) was measured for comparison and texture evaluation of different samples (Fig. 9).

3.2.5.6 Color Measurement

L-, a- and b- scale of Hunterlab Colorimeter Model D25L-2 (Hunterlab Colorimeter, J.B. Atlas Co., Ltd., Rexdale., Ont.) was standardized with a white plate before use. Subsequent calibration was made with color plates against the standard values. A uniform quantity of the sample was filled into the sample dishes and L-, a- and b- values were recorded.

3.2.5.7 Calcium Determination

The Ca^{2+} was determined as per AOAC methods (1980) with slight modifications. One g ground hash-brown potatoes were charred at 200°C for 30 minutes, then ashed for 2 hours. Each sample was then cooled, wetted with a few drops of HNO_3 (1+1), and ashed for one hour. The residue was cooled in a desiccator and was dissolved in 10 ml HCl (1+1). Analysis for Ca^{2+} was performed in the presence of of lanthanum chloride using an atomic absorption spectrophotometer (ASS).



Test Parameters

Fixture:	Kramer Shear Cell
Drive Speed:	20 cm/min
Chart Speed:	10 cm/min
Force Range:	50 Kg Full Scale

Figure 9. Texture Evaluation of Rehydrated Hash-Brown Potatoes using Instron Universal Testing Instrument.

3.2.5.8 Sensory Evaluation Tests

Sensory evaluation tests of products with respect to texture, flavor and overall acceptability were conducted. The three hash-brown potato samples being tested were :

I. Experimental product, dehydrated hash-brown potatoes obtained from the process under investigation.

II. Commercial Dehydrated hash-brown potatoes obtained at a local outlet (Idahoane , Idaho Fresh-Pak, Inc., Lewisville, IH).

III. Hash-browns prepared from fresh potatoes, (Netted Gem potatoes, S.G 1.098).

Hash-browns from dehydrated samples were prepared according to commercial procedure. A known quantity of product (85g) was cooked uncovered with a measured amount of water, margarine, salt and sugar in a skillet over medium high heat until the water was absorbed. The poatoes were then browned on each side.

The control sample was prepared, using Netted Gem potatoes, by cooking and browning the peeled, trimmed, grated and washed potatoes in a skillet with water, margarine, salt and sugar at the same ratio as products prepared from dehydrated potatoes.

Two sessions of preference test were conducted in a sensory evaluation room. For each session, 12 panelists were selected from the staff, students, and technicians in the Department of Food Science. The judges were asked to score the samples on a nine point hedonic scale on the scoring sheet (Fig. 10). The coded samples were reheated in microwave oven before serving. The order in which the three samples were served was balanced so that each possible order was used twice : ABC, ACB, BAC, BCA, CAB, CBA (Larmond, 1977). Different coding was used for each sample.

The results were then analysed with the analysis of variance, Duncan's Test, and correlation with the aid of APL program on the University MTS Computer.

Questionnaire for

Scoring

Name :..... Date .....

Product : Hash-brown Potatoes

Scoring Method : Taste these samples and insert appropriate score for each attribute under each sample.

Score	Description
9	--- Excellent (like extremely)
8	--- Very good (like very much)
7	--- Good (like moderately)
6	--- Acceptable (like slightly)
5	--- Borderline (neither like nor dislike)
4	--- Slightly acceptable (dislike slightly)
3	--- Moderately unacceptable (dislike moderately)
2	--- Very unacceptable (dislike very much)
1	--- Awful (dislike extremely)

Please taste samples in the order given below :

Attribute	Sample No
A. Texture	
B. Flavor	
C. Acceptability	

Figure 10. Scoring Sheet for Sensory Evaluation.

4. RESULTS AND DISCUSSION

4.1 Drying-rate

In the present experiment, the prepared potatoes were subjected to a series of pretreatments before they were dried in a fluid-bed dryer. Many intial trial runs were done with the fluidized bed dryer before the ideal processing conditions were obtained. The present modifications of the equipment (insulation and installation of stirrer) were effected to achieve maximum efficiency of the dryer. The drying conditions were set to achieve maximum drying rate which was accomplished by using high drying air temperature and high air velocity, while the potatoes were slowly stirred. The heat and mass transfer rates in the bed were sufficiently high so that the temperature of the potatoes were kept low corresponding to the wet bulb temperature during the constant-rate period. After 15 to 20 minutes of drying, the product was fluidized in the air stream at the moisture content of approximately 50% (wet basis) and air velocity of about 140 m/min.

The results reported in Tables 4, 5, 6 and 7 are those obtained under most ideal conditions with the present equipment. In samples reported in Tables 4 and 5, it was found that the moisture content of the prepared potatoes (wet load) before dehydration was much higher than that of raw potatoes, being about 85-86%. This was due to the adherence of water to the surface of potato slices after washing or soaking in pretreatment solutions. Subequently, a slight modification in the process was made, i.e. the potatoes after pretreatments and soaking were drained and centrifuged at 1000 rpm for five minutes to remove the surface water. Approximately 5% of total moisture was reduced by the centrifugation (Run Nos. 3 and 4). This helped to standardize moisture content of wet loads and to reduce the load of drying. This also improved the drying ratio as can be seen from the results in Tables 6 and 7.

The drying rate curves of four samples (Run Nos. 1,2,3 and 4) are presented in Fig. 11. In all cases the drying was accomplished within one hour. The dried products attained final moisture content between 6 to 7% (wet basis) within one hour of drying except those samples

Table 4

Processing Conditions of Laboratory Prepared Hash-brown Potatoes

Run No :	1	Cultivar :	Netted Gem Potatoes
Wet Load :	2 Kg		(S.G 1.098)
Pretreatments :	Control	Inlet Air Velocity :	150 m/min
	(Precooked, No Ca^{++})	Dry Bulb Temp :	21°C (Inlet Air)
Drying Ratio :	7	Wet Bulb Temp :	16°C (Inlet Air)

Drying time, Min	Drying Air Temp °C		Air Mass Flow Rate	Drying Rate	Product Moisture %	
	Below Bed	Above Bed	Kg/Min	Kg.Water/Min	Observed	Calculated
0.0	72	60	9.359	0.0449	86.00	
2.0	"	49	"	0.0898		
5.5	"	49	"	0.0898		81.83
20.5	"	65	"	0.0309		57.12
26.5	"	70	"	0.0103		47.76
45.0	"	71	"	0.0066		
60.0	"	71	"	0.0066	6.10	

Table 5

Processing Conditions of Laboratory Prepared Hash-brown Potatoes

Run No :	2	Cultivar :	Netted Gem Potatoes (S.G 1.098)
Wet Load :	2 Kg		
Pretreatments :	Precooked (200 ppm Ca^{++})	Inlet Air Velocity :	139 m/min
		Dry Bulb Temp :	21°C (Inlet Air)
Drying Ratio :	7	Wet Bulb Temp :	15°C (Inlet Air)

Drying Time, Min	Drying Air Temp °C		Air Mass Flow Rate	Drying Rate	Product Moisture %	
	Below Bed	Above Bed	Kg./Min	Kg. Water/Min	Observed	Calculated
0	67	50	8.815	0.0591	85.78	
1	"	43	"	0.0864		
7	"	43	"	0.0864		79.33
21	"	57	"	0.0308		51.45
33	66	64	"	0.0097		19.03
43	"	65	"	0.0044		
45	68	66	"	0.0018		
60	68	67	"	0.0018	7.23	

Table 6

Processing Conditions of Laboratory Prepared Hash-brown Potatoes

Run No :	3	Cultivar :	Netted Gem Potatoes
Wet Load :	1.75 Kg		(S.G 1.098)
Pretreatments :	Soaked in	Inlet Air Velocity :	146 m/min
	0.25% Surfactant	Dry Bulb Temp :	23°C (Inlet Air)
Drying Ratio :	5	Wet Bulb Temp :	19°C (Inlet Air)

Drying Time Min	Drying Air Temp °C		Air Mass Flow Rate	Drying Rate	Product Moisture %	
	Below Bed	Above Bed	Kg./Min	Kg. Water/Min	Observed	Calculated
0	75	60	9.045	0.0534	80.00	
1	"	53	"	0.0769		
9	"	53	"	0.0769		66.95
14	"	65	"	0.0371		
26	"	71	"	0.0091		30.27
30	"	76	"	0.0063		26.32
38	"	79	"	0.0036		
45	"	79	"	0.0036	5.56	

Table 7

Processing Conditions of Laboratory Prepared Hash-brown Potatoes

Run No :	4	Cultivar :	Netted Gem Potatoes
Wet Load :	1.75 Kg		(S.G 1.098)
Pretreatments :	Soaked in	Inlet Air Velocity :	149 m/min
	0.25% Surfactant	Dry Bulb Temp :	23°C (Inlet Air)
	+ 5% Glycerol	Wet Bulb Temp :	21°C (Inlet Air)
Drying Ratio :	5		

Drying Time Min	Drying Air Temp °C		Air Mass Flow Rate	Drying Rate	Product Moisture %	
	Below Bed	Above Bed	Kg./Min	Kg. water/Min	Observed	Calculated
0	75	57	9.210	0.0699	80.00	
1	"	53	"	0.0838		
6	"	53	"	0.0838		71.98
14	"	66	"	0.0414		54.19
26	"	73	"	0.0083		25.06
36	"	74	"	0.0046		
45	"	74.5	"	0.0018		
60	"	74.5	"	0.0018	6.84	

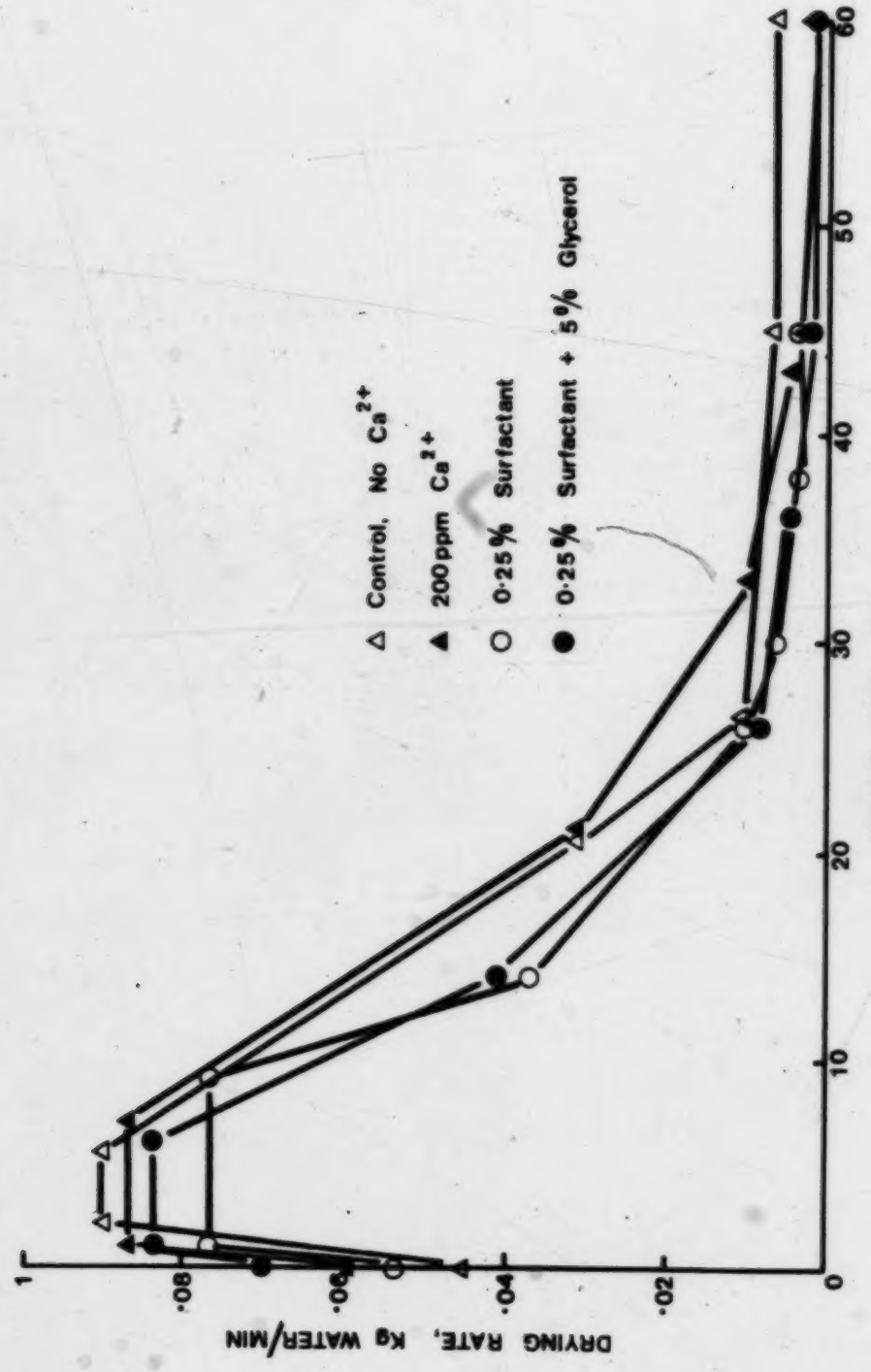


Figure 11. Drying Rate Curve of Hash-brown Potatoes.

which were dipped in higher concentration of glycerol.

The glycerol soaking treatment did not improve drying characteristics. In fact those products dipped in 10, 15 and 20% glycerol retained moisture of 10% or higher after one hour of drying and would take a much longer time to bring it down to 6 - 7%. This was primarily due to the humectant property of glycerol.

Constant-rate drying periods of various samples (in triplicate) were compared using Duncan's Test on MTS computer (APL program). Potatoes treated with 0.25% surfactant and 200 ppm Ca^{2+} in the form of $CaCl_2$ solution recorded longer constant rate periods of 6 to 8 minutes as compared with control (without calcium treatment) of only 2-3 minutes (Table 8). At 95% confidence level, 0.25% surfactant was found to be better than the control and other pretreated samples in extending the constant-rate period.

In the precooking treatment, potatoes were precooked in Ca^{2+} solution in order to strengthen cell wall and middle lamella in the tissue, prior to steam cooking. Haydar *et al* (1980) found that 100 ppm Ca^{2+} in precooking and cooling water gave maximum firmness of the tissue. Calcium content was also determined in calciumm treated, untreated and commercial samples (Table 9). The calcium content in lab-product that had been treated with 200 ppm Ca^{2+} in $CaCl_2$ solution was found as 800 ppm (wet basis). The untreated sample was found to contain 457 ppm and the commercial sample 537 ppm. Chung (1979) reported that Ca^{2+} content of Alberta grown potatoes (Netted Gem) varies from 350 to 420 ppm (dry basis). According to U.S Army and Federal Specifications (1979), such dehydrated products may contain 0.3 (3000 ppm) $\pm$ 0.1 (1000 ppm) per cent.

In this work when using shredded potatoes of approximately (12.7 - 38.1) x 8 x 1.5 mm size, it was found that 200 ppm Ca^{2+} for precooking and cooling followed by 10 minutes steam cooking offered the best drying characteristics, i.e. long constant-rate period.

Dipping cooked potato samples in surfactant (Myvatex®) emulsion for 30 minutes resulted in shortening of overall drying time (45 min) to attain 6% moisture content (Fig 11). Among different levels of surfactant emulsion tried, i.e. 0.1. 0.25, 0.5%; 0.25% was found to be

TABLE 8

Comparison of Constant Rate Drying Periods of Different Samples (Time in Minutes)

No. of Replication	Control Samples		Surfactant Treatment %			Combined Surfactant and Glycerol Treatment (%)	
	No Ca^{++}	200 ppm Ca^{++}	0.1	0.25	0.5	0.1 + 5	0.25 + 5
1	2	6	5	6	5	7	5
2	3	7	4	8	5	6	6
3	3	6	5	8	5	3	5
Mean[1]	2.6 ± 0.3	6.3 ± 0.3	4.6 ± 0.3	7.3 ± 0.6	5 ± 0.0	5.3 ± 1.2	5.3 ± 0.3

[1]Mean of three samples ± Standard error.

TABLE 9

Calcium Analysis of Dehydrated Hash-brown Potatoes[1].

Treatment	Ca^{2+} in treatment Solution (ppm) [2]	Ca^{2+} found (ppm)
1. Untreated (control), precooking 20 min/70°C, steam cooking 10 min	0	477.5 ± 29.0
2. Treated sample, precooking 20 min/70°C in $CaCl_2$ sol, steam cooking 10 min	200	800.0 ± 57.7
3. Commercial sample	Not known	537.5 ± 3.5

[1] Wet basis

[2] Avg. of two samples (3 replicates each) ± s.d.

the optimum level with respect to drying characteristics of the samples. A higher concentration (0.5%) did not further improve drying.

Both combined treated samples, one soaked in 0.1% surfactant + 5% glycerol solution and the other one in 0.25% surfactant + 5% glycerol, recorded similar constant-rate periods of approximately 5 minutes; and were significantly better than the control (without Ca^{2+} treatment) sample. Therefore, combined treatment of 0.1% surfactant and 5% glycerol was chosen from this trial, as lower surfactant concentration would be a saving in the production cost.

Calcium treated samples gave better dehydration characteristics. This might be due to the fact that treated potato pieces retain their integrity, whereas untreated samples appeared to be more fragile having greater degree of breakage (Table 14). There was also a somewhat greater degree of shrinkage of the control sample as indicated by its slightly higher bulk density (Table 15) as compared to the treated product. The collapse of the internal structure of the tissue would, therefore, impede the movement of water during drying.

Glycerol is known to possess water retention property, under conditions of medium and high relative humidity (Griffen and Lynch, 1972). Addition of glycerol at high concentration would impart this humectant effect significantly on the product. Higher levels of glycerol would also not be desirable in dehydrated potatoes as it tends to sweeten the product.

Monoglycerides are known to complex readily with solubilized starch. The exact mechanism of how the surfactants act to increase the drying rate is not clear. Heyman (1968) used acetylated monoglycerides as heat transfer agents at low temperature under vacuum for dehydration of mushrooms. He claimed that acetylated monoglycerides penetrate into the cells and interstices of the foods so that they transmit heat to foods which are not finally divided and thus accelerate their dehydration. Roth and Loncin (1983) reported that surfactants such as monoglycerides inhibit evaporation in a 2% agar gel solution. However, agar gel is a homogeneous system with a continuous three dimensional network that holds a great quantity of water through strong hydrogen bonding as well as physical entrapment. Transfer of water

through gel structure during drying is largely by diffusion, not by capillary movement. Therefore, reduction of surface tension by surfactants would not have a significant effect on the drying rate of the gel. In fact, the hydrophobic tail of the monoglycerides may inhibit the evaporation, as Roth and Loncin (1983) found, possibly by forming a thin layer of oil-like film on the gel surface. Therefore, no chemical complex between agar and surfactant is expected to form that may influence drying rate.

The same phenomena would not apply in the case of cooked potatoes treated with surfactant. Potato tissue, though quite homogeneous, contains fibrous materials which form the framework of cell wall. On cooking starch granules gelatinize to fill the cell and distend the cell wall. Part of the starch gel, especially amylose, leaks out from the cell through cell pits (Reeve, 1954a) into the interstices and out to the surface of the slices, causing some stickiness. It is possible that during drying the leaked gel would form an obstruction against moisture transfer through intersticial voids and evaporation from the surface. This hypothesis is supported by Saravocos and Charm (1962) who found that capillary forces were not important in the dehydration of potatoes.

On the other hand, if the leaked starch gel is prevented from forming a continuous network in the interstices and surface of sliced potatoes by allowing it to form clathrates with monoglycerides, drying of the potato pieces would be accelerated. This was corroborated by the evidence presented in Table 8 when cooked sliced potatoes were treated with increasing concentrations of surfactant emulsion. The constant-rate period increased until it reached the maximum at 0.25%. Higher monoglyceride concentration appeared to depress the constant-rate period. If could be hypothesised that at 0.25% monglycerides the leaked starch was optimally complexed to allow maximum free movement of water vapor during drying. At higher concentration, however, the surfactant might itself become a barrier against the moisture transfer by forming a thin layer over the product surface and, possibly, block the passages in the interstices, thus reducing the lengths of the constant rate period.

In order to combine the benefits of surfactant treatment with that of glycerol, i.e. to maximize the drying rate of the product while minimizing the breakage,. emulsion of monoglycerides and glycerol at two concentrations were used to treat the samples. Cooked sliced potatoes were soaked in the emulsions of 5% glycerol and 0.1% Myvatex®, and 5% glycerol and 0.25% Myvatex® for 30 min. As shown in Table 8, constant-rate period of the samples so treated was increased and was significantly larger than-that of the control. However, Duncan's Multiple Range Test did not show a significant difference in the drying rate among the samples variously treated. Of course, an extension of the constant rate period was not the only benefit expected from these treatments. Their effects on other characteristics of the product will be discussed subsequently.

Inspite of the what has been shown to be the beneficial effect of freezing and thawing treatments in accelerating the drying rate of potato granules (Ooraikul, 1973), cooling, freezing and thawing did not appear to improve drying or other characteristics of hash-brown potatoes. Cooked, frozen and thawed potato tissue was subdivided into very small units of single cells or aggregates of a few cells in the granule processing. Therefore, the effect of the treatments on individual cells was more pronounced when they were dried as the cell mass took on the characteristics of wet sand in which capillary movement of water during drying was the major mechanism. In the slices, however, this was not the case. The treatments did not improve drying rate of the product. In fact, breakage of the dried product increased with these treatments. Therefore, the methods were dropped from further study.

4.2 Rehydration characteristics

Table 10 shows the effect of precooking, cooking and calcium treatments on rehydration characteristics of hash-brown potatoes. The samples, precooked in $CaCl_2$, retained better shape and integrity than those of control samples (no precooking or Ca^{2+} treatment). The pretreatments with 200 ppm of calcium and 10 minutes of steam cooking achieved the highest rehydration values (R.R. = 7.0). Higher concentration of calcium (400 ppm)

Table 10

Effect of Precooking, Cooking and Ca^{++} Treatment on Rehydration Characteristics[1] of Hash-brown Potatoes

Predrying Treatment			Dehydration Ratio	Rehydrated[2] Weight (g)	Rehydration Ratio	Coefficient of Rehydration	Moisture in Rehydrated Sample (%)
Precooking at 70°C		Steam Cooking Time, Min	D. R.	W_r	R. R.	C. R.	W_{rm}
Time, Min	Ca^{++}, ppm						
(1) 20 (control)	None	10	4.7	62.8 ± 1.7	6.3	126.4	84.2
(2) Commercial Sample[3] (Idahoan)				46.2 ± 1.6	4.6	92.9	78.5
(3) None	None	10	4.7	79.9[4] ± 7.9	7.6	152.7	86.9
(4) 20	None	None	4.6	63.6 ± 0.1	6.4	128.1	84.4
(5) 20	None	20	4.6	69.4 ± 1.1	7.0	139.8	85.7
(6) 20	200	0	4.6	64.6 ± 1.8	4.5	130.3	84.6
(7) 20	200	10	4.6	70.2[4] ± 0.8	7.0	141.4	85.9

Contd ...

Table 10 (contd.)

Effect of Precooking, Cooking and Ca^{++} Treatment on Rehydration Characterisites[1] of Hash-brown Potatoes

Predrying Treatment			Dehydration Ratio	Rehydrated[2] Weight (g)	Rehydration Ratio	Coefficient of Rehydration	Moisture in Rehydrated Sample (%)
Precooking at 70°C		Steam Cooking Time, Min	D. R.	W_r	R. R.	C. R.	W_{rm}
Time, Min	Ca^{++}, ppm						
(8) 20	200	20	4.7	67.4 ± 1.1	6.7	135.7	85.3
(9) 20	400	0	4.6	61.9 ± 3.1	6.2	124.7	84.0
(10) 20	400	10	4.6	67.0 ± 0.9	6.7	135.0	85.2
(11) 20	400	20	4.6	65.3 ± 0.2	6.5	131.5	84.8

[1] See equations I, II, III, & IV under "Materials and Methods"

[2] Mean of two samples ± Standard error

[3] Rehydration characteristics of commercial sample calculated on the basis of % moisture (w.b) in material before dehydration as 80%.

[4] Significant difference as compared with control at 5% level.

supressed the water absorption (R.R. = 6.7). Cooking time generally increased the water absorption, but 20 minutes cooking time gave a softer product. The sample with no precooking, but steam-cooked for 10 minutes absorbed more water (R.R.= 7.6) than the control. However, the rehydrated product became soft and mushy, and consequently was not found suitable for making hash-browns. Precooking in $CaCl_2$ solution (400 ppm Ca^{2+}), and without steam cooking resulted in tough and hard product with minimum water absorption (R.R. = 6.2).

The rate of rehydration was observed to be also influenced by product dimensions (Fig. 12). Two sets of dimensions were compared, i.e (12.7 - 38.1) x 8 x 1.5 mm and (12.7 - 38.1) x (6.35 - 12.7) x 3.2 mm. After 3o minutes of rehydration time, one g of the former absorbed 5.3 g of water, whereas the same amount of the later absorbed 4.3 g. Commercial hash-browns absorbed 3.6 g of water per g of sample over the same time interval.

The samples treated with more than 5% glycerol absorbed less water (Table 11). The increase in glycerol concentration tended to decrease water absorption in most cases. At 1 to 5% glycerol level, no significant difference in rehydration characteristics was found between glycerol treated and control samples. No distinct relationship seems to exist between the increase in soaking time and water absortion on rehydration. However, the soaking of product in 1% glycerol solution for 6 hour gave higher water absorption, but the difference was only marginal as compared with control. The glycerol treatment mainly contributed to the reduction in the breakage of the finshed product. Accordingly, the soaking of potatoes in 5% glycerol for 30 minutes appeared optimum in minimizing the breakage without having any significant effect on rehydration quality.

No significant difference was noticed in the rehydration characteristics when the product was soaked in surfactant or in combined surfactant and glycerol emulsion (Table 12). The surfactant emulsion at 0.1% was found to be optimum in terms of rehydration rate (Fig 13). The water absorption capacity decreased as the surfactant concentration increased to 0.5%. The soaking of potatoes in glycerol alone, as pointed out, resulted in lower rehydration but

Table 11

Effect of Soaking Precooked and Cooked Potatoes (8 mm size Shreds) in Various Glycerol Solutions before Drying on Subsequent Rehydration Characteristics.[1]

Glycerol soaking treatment[2]		Dehydration Ratio	Rehydrated[3] Weight	Rehydration Ratio	Coefficient of Rehydration.	Moisture in Rehydrated Sample
% Glycerol	Time, h	D. R.	(g) W_r	R. R.	C. R.	(%) W_{rm}
(1) None	None	4.7	62.8 ± 1.7	6.3	126. 4	84.2
(2) 1	1/2	4.6	57.9 ± 0.6	5.8	116.8	82.8
(3) 5	"	4.7	55.5 ± 0.4	5.2	104.2	80.8
(4) 10	"	4.5	47.6[4] ± 0.0	4.8	96.2	79.2
(5) 1	1	4.6	55.5 ± 1.4	5.6	111.8	82.1
(6) 5	"	4.7	56.7 ± 1.2	5.7	114.2	82.5
(7) 10	"	4.3	46.7[4] ± 1.0	4.7	94.7	79.6
(8) 1	3	4.6	63.6 ± 1.5	6.4	128.2	84.4
(9) 5	"	4.7	54.2 ± 2.6	5.4	109.2	81.7
(10) 10	"	4.4	54.2 ± 0.2	5.4	109.8	81.8
(11) 1	6	4.6	67.1[4] ± 0.2	6.7	135.2	85.2
(12) 5	"	4.6	58.7 ± 0.7	5.9	118.2	83.1
(13) 10	"	4.3	46.9[4] ± 0.2	4.7	95.2	79.0

[1] See equations I, II, III, & IV under "Materials and Methods".

[2] At ambient temperature.

[3] Mean of two samples ± standard error.

[4] Significant difference as compared with control at 5% level.

Table 12

Effect of Surfactants, and Combined Surfactant and Glycerol, on Rehydration Characteristics[1] of Hash-brown Potatoes

S.No	Pretreatment[2]			Dehydration Ratio D.R.	Rehydration Weight[3] (g) W_r	Rehydration Ratio R.R.	Coefficient of Rehydration C.R.	Moisture in Rehydrated Sample (%) W_{rm}
	% Surfactant	% Glycerol	Soaking Time, h					
1	None	None	None	4.7	62.8 ± 1.7	6.3	126.4	84.2
2	0.1	None	1/2	5.3	67.4 ± 1.5	6.7	135.8	85.3
3	0.25	None	1/2	5.2	62.5 ± 2.6	6.3	126.1	84.1
4	0.5	None	1/2	5.4	60.7 ± 0.1	6.1	122.1	83.6
5	0.1	5	1/2	5.3	63.5 ± 0.6	6.3	127.8	84.3
6	0.25	5	1/2	5.3	61.1 ± 2.3	6.1	123.6	83.8

[1] See equations I, II, III & IV under "Materials and Methods".

[2] At ambient temperature.

[3] Mean of two samples ± standard error.

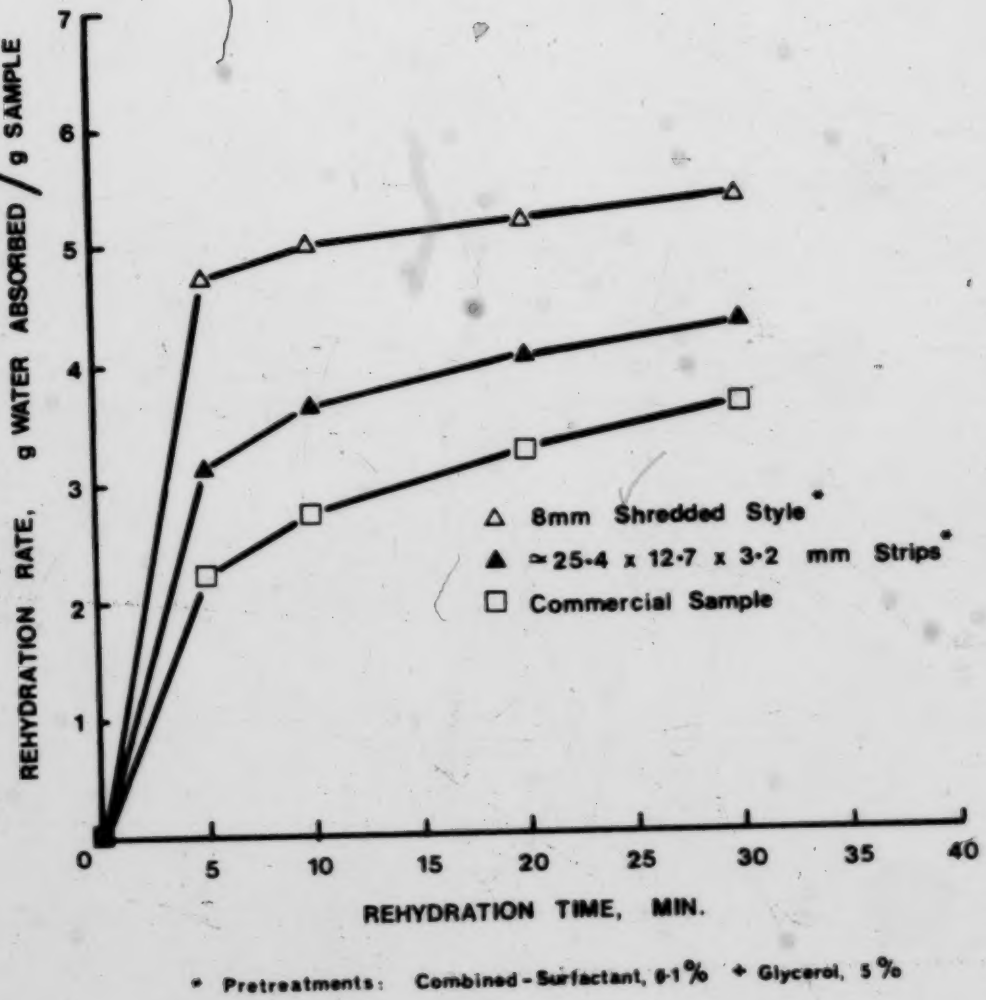


Figure 12. Influence of Piece Size on Rate of Rehydration.

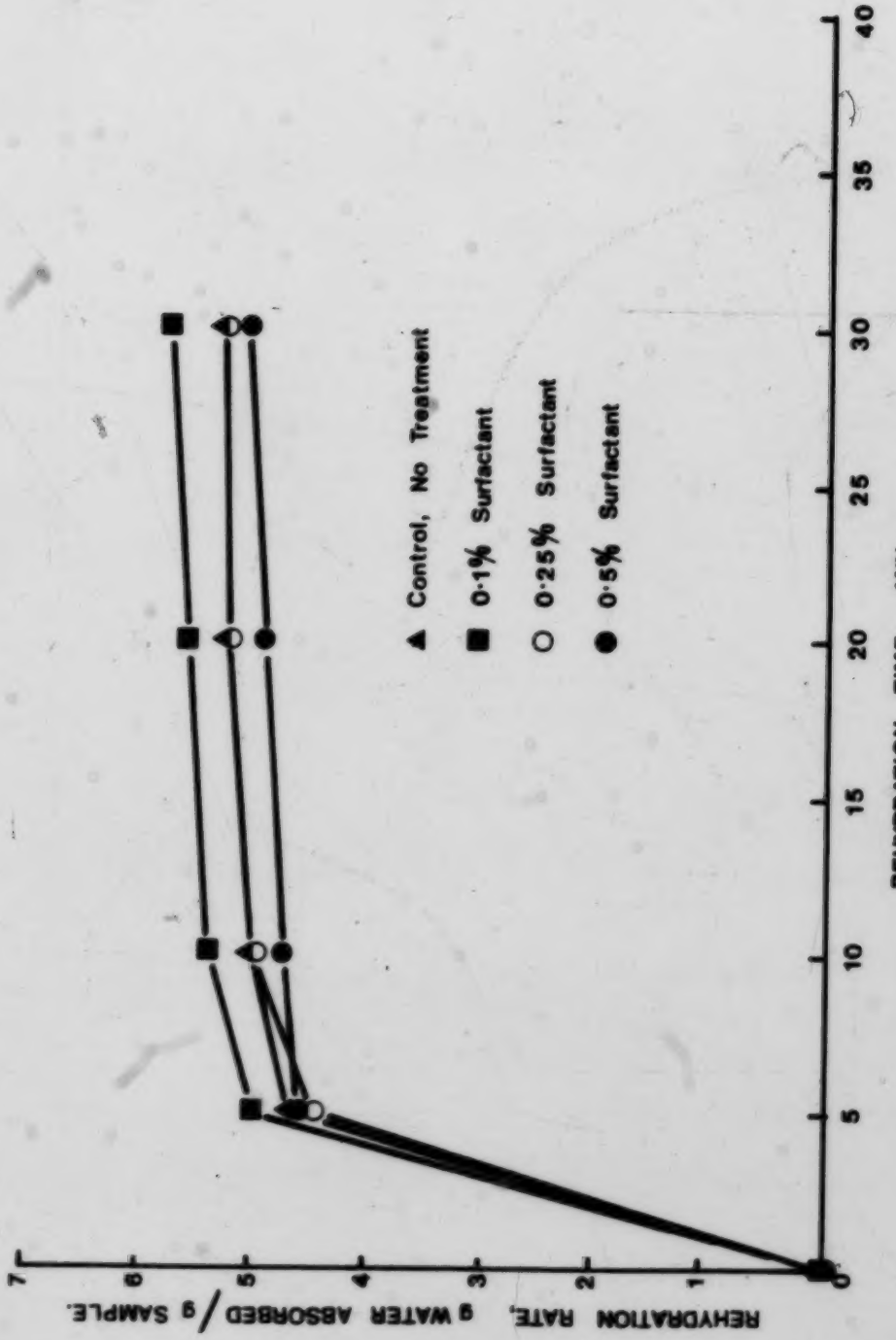


Figure 13. Effect of Surfactants on Rehydration Rate of Dried Hash-brown Potatoes.

rehydration capacity was regained in the combined glycerol and surfactant treatment (Fig. 14). The soaking of potatoes before dehydration in combined surfactant (0.1) and glycerol (5%) emulsion gave the rehydration values almost equal to the control sample. Higher concentration of surfactant (0.25%) with glycerol slightly suppressed the rate of rehydration.

Table 13 provides the comparison between rehydration characteristics of lab-prepared product (0.1% surfactant + 5% glycerol) and commercial sample (Idahoane-Idaho, Fresh-Pak Inc.,Lewisville, Idaho, USA). The data show that trial sample absorbed 49.9 g of water in 10 minutes whereas commercial product imbibed only 27.4 g of water during the same period of time. After 20 minutes of rehydration, there was almost no further increase in weight of laboratory product, but commercial sample continued to absorb water even after 30 minutes (Fig. 15). According to U.S Army and Federal Specifications (1979), the thin sliced dehydrated products such as hash-brown potatoes need to be rehydrated completely within 25 minutes. Coefficient of rehydration of the experimental sample was 37% greater than that of the commercial sample after 30 minutes of rehydration. Similarly, the moisture in rehydrated material was 6% more than in the commercial product. The rehydration ratio of laboratory sample was also higher than that of the commercial sample (6.4 vs 4.6).

One of the important criteria in assessing the quality of dehydrated sample is that the product should rehydrate approximately to its original shape and size in a short time. The rehydrated potato products with high water absorption have been found most acceptable with respect to organoleptic quality (Simpson *et al.*, 1955a).

Many factors such as loss of diffential permeability in the protoplasmic membrane, loss of turgor pressure in the cell, protein denaturation, starch crystallinity and hydrogen bonding of macromolecules have been suggested as causes of and, at times, correlated with various parameters of rehydration (Neumann, 1972). It is generally accepted that excessive heat destroys the osmotic properties of the cell and cell turgor, thereby affecting the ability of the tissue to absorb and to retain water. Gane and Wager (1958) reported that the elasticity of cell walls is important for good rehydration and that any substantial amount of heat treatment

TABLE 13

Comparison of Rehydration Characteristics[1] between Laboratory Prepared (Fluid-bed Dried) and Commercial Hash-brown Potatoes

% Moisture (raw material)	Dehydrated Weight (g)	Dehydrated Moisture (%)	Rehydration Time (Min)	Rehydrated Weight[2] (g) W_r	Rehydration Ratio R.R.	Coefficient of Rehydration C.R.	Moisture in Rehydrated Sample (%), W_{rm}
	Fluid-bed Dried Sample[3]						
80	10	6	5	57.1 ± 0.9	5.7	114.9	82.6
"	"	"	10	59.9 ± 0.9	6.0	120.5	83.4
"	"	"	20	61.6 ± 0.9	6.2	123.9	83.9
"	"	"	30	63.5 ± 0.6	6.4	127.8	84.3
	Commercial Sample						
80[4]	10	5	5	32.4 ± 0.5	3.2	65.1	69.3
"	"	"	10	37.4 ± 2.0	3.7	75.2	73.4
"	"	"	20	42.8 ± 1.8	4.3	86.0	76.8
"	"	"	30	46.2 ± 1.6	4.6	92.9	78.5

[1] See equations I, II, III, & IV under "Materials and Methods".

[2] Mean of the samples ± Standard error.

[3] Pretreatments : Combined-surfactant (0.1%) + glycerol (5%).

[4] Actual % moisture of raw material used in commercial sample is not known, 80% was therefore, assumed.

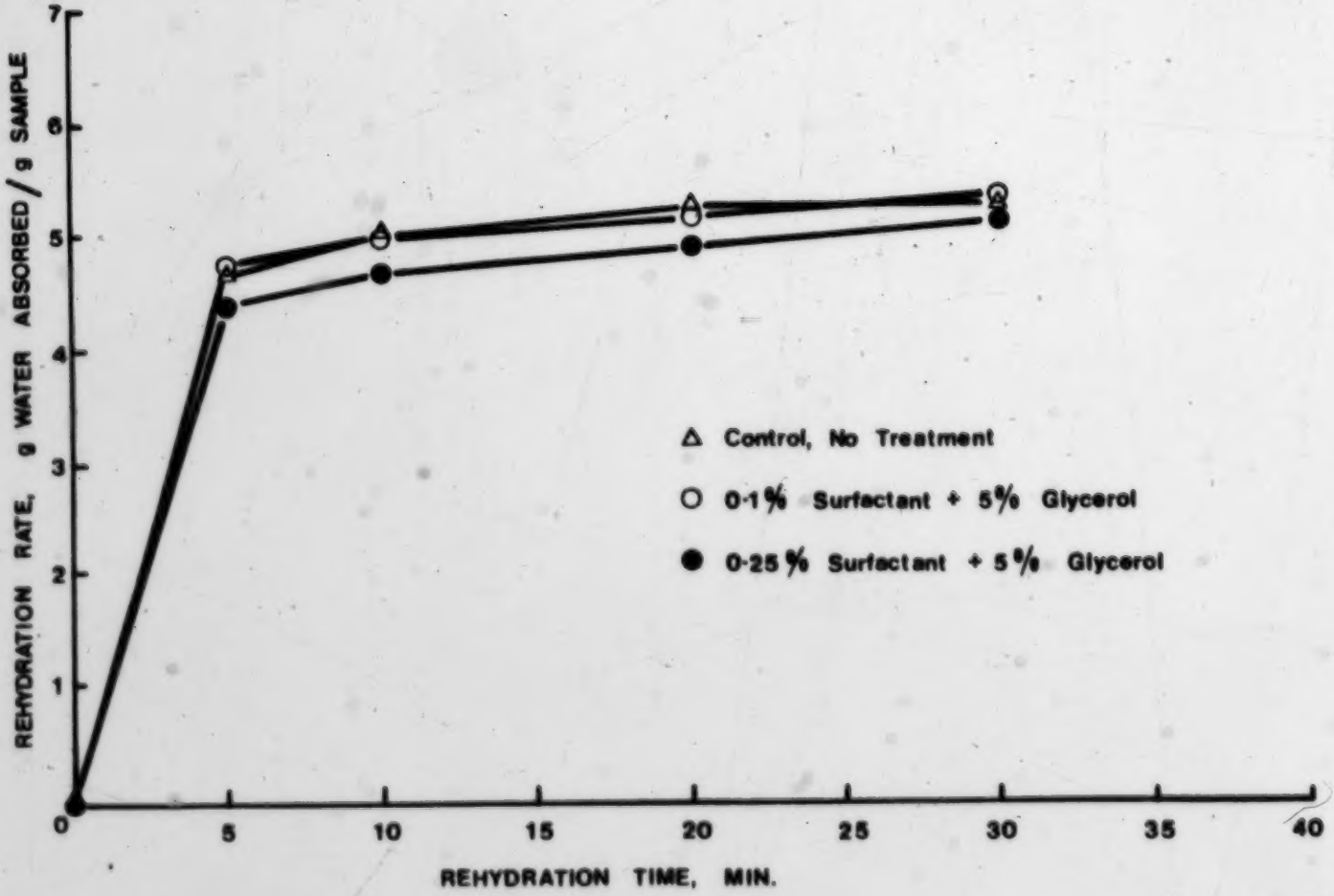


Figure 14. Effect of Combined Predrying Treatments, Surfactants and Glycerol on Rehydration Rate of Hash-brown Potatoes.

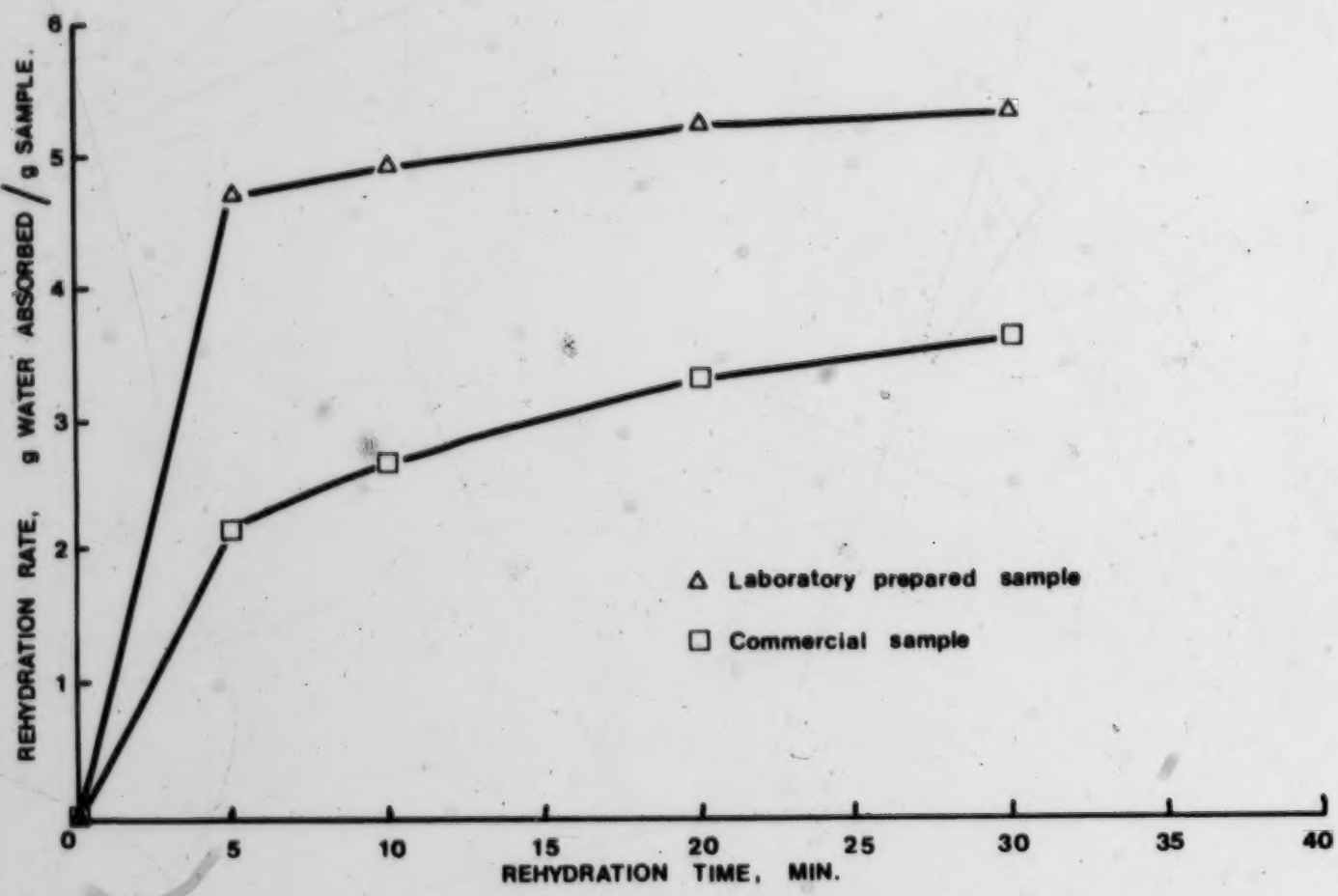


Figure 15. Comparison of Rehydration Rate between Commercial and Laboratory Prepared Samples.

reduces this elasticity. However, a different viewpoint has been presented by other workers (Sterling and Shimazu, 1961; Sterling, 1963) suggesting that water blanching increases the amorphous content of cell-wall cellulose. The higher amorphous content allows the intact cell walls to more readily absorb water, swell and assume their original shape, resulting in improved reconstitution. In fact, Sterling (1955) observed that cell walls are not destroyed by heat and moisture in the cooking process, even if vegetables such as potatoes are steamed for up to one hour.

In the present experiment, steam cooking increased rehydration rate and was also noted by other workers in vegetable dehydration (Neumann, 1972; Srivastava and Sulebele, 1975). Gooding (1956) has found higher product yields of vegetable with steam blanching than water blanching. In starchy vegetables like potatoes, the steam cooking causes swelling and gelatinization of starch, reduces starch crystallization and thus prepares the product for better reconstitution. Calcium treatment maintains integrity of potato pieces during handling and dehydration. It is postulated that excessive breakage may cause breakage of cells and leaching of soluble amylose, and forming a layer on the surface which is impregnable to water absorption. Less breakage due to strengthening of middle lamella with the addition of calcium ions improved the recontitution characteristics. Excessive concentration of calcium (400 ppm) suppressed the rehydration with toughening of the tissue and potato pieces due to the formation of calcium pectinate (Simpson *et al.*, 1955b).

The crystalline content of the cell-wall plays an important role in swelling and water absorption. The highly crystalline substances swell poorly and absorb less water. Earlier researchers (Shimazu and Sterling, 1961) have shown that crystallinity increases in gels of cellulose and of calcium pectinate during dehydration.

The size and shape of vegetable pieces have a considerable effect on rate of dehydration and rehydration characteristics of the dried products. Simon and Coworkers (1953) have shown improvement with decreased size of potato pieces. Davis and Howard (1943) have reported on the effect of slice thickness on the rehydration rate of dried carrots. They showed that rate of

rehydration is directly proportional to the surface-volume and surface-weight ratios of the product, i.e the greater the surface area the faster the water is absorbed into the product. The results from the present rehydration experiment with two product sizes agree with these findings. However, no significant difference was detected in the rate of dehydration between the products of two different sizes used.

Addition of edible polyhydroxyl compounds into fruit and vegetable tissue prior to dehydration has been found to improve reconstitution characteristics such as more rapid and complete rehydration, firmer texture and size and shape more similar to the undehydrated product. (Pader and Lauro, 1966; Savage, 1967). Neumann (1972) has found that glycerol has improved the rehydration charcateristics in the dehydration of celery. In the present study, it was found that less water was absorbed with the incorporation of higher concentration of glycerol into the product. However, the rate of rehydration was faster and the product retained better shape as compared to the control. Srivastava and Sulebele (1975) have also found no distinct difference in rehydration of cauliflower product with glycerol treatment prior to dehydration. In fact they noticed that the dried product had higher moisture content. Samples treated with higher glycerol concentrations appeared to retain more moisture after dehydration, thus affecting the degree of water reabsorption on rehydration. However, the product regained the shape and size more fully. The hydroxyl groups of glycerol may act by reducing the hydrogen bonding sites on the cell wall polysaccharides, thus preventing excessive shrinkage or cell deformation (Neumann, 1972).

Surfactants such as monoglycerides are known to complex readily with soluble amylose (Bourne *et al.*, 1960; Hoover and Hadziyev, 1981). Myvatex® at 0.1% level was found optimal for improving the rehydration characteristics of hash-brown potatoes. A small amount of surfactant was sufficient to complex the amylose (leached soluble starch) to inhibit the formation of a continuous film on the surface. Soluble starch is believed to form a thin film and seal the pores in the dried potato products. This might be responsible for reduced rate of rehydration. However, a high concentration of surfactant (0.25% and 0.5% in Fig. 13)

supressed water absorption. Perhaps, the extra quantity of surfactant which did not complex with amylose, decreased the rehydration by forming a thin hydrophobic film on the product surface.

4.3 Breakage of product

Table 14 shows per cent breakage of samples subjected to various pretreatments. The control sample with no precooking treatment had the highest breakage of 19.3%. This was reduced to 10.6% with precooking of potatoes in 200 ppm calcium chloride solution. This is primarily due to strenghening of potato tissue by Ca^{2+} during precooking and cooling treatment (Haydar *et al.*, 1980; Moledina *et al.*, 1981). This contributed to firmer texture. Various other combinations of precooking and cooking treatments did not significantly improve breakage.

Glycerol treatment appeared to have the most significant effect in reducing breakage of the product. The breakage was reduced to 6.7, 5.4, and 4.6% by dipping potatoes for 30 minutes in 1, 5, and 10% glycerol solution respectively. Soaking time in glycerol solution did not significantly effect per cent breakage, and therefore, dipping time was reduced to 30 min from six hours. Glycerol, an effective humectant, replaces part of the water in cell structure thereby preventing excessive collapse of the tissue during drying and keeping the product moist and pliable. Minimum shrinkage or cell dehydration was assumed responsible for reduced breakage of the product. This may be due to the fact that addition of hydroxyl groups of polyhydroxy compounds such as glycerol that may minimizes hydrogen bonding of the cell wall polysaccharides (Neumann, 1972).

Surfactants also reduced breakage of the product as compared to control sample. However, the product breakage increased with the increase in surfactant concentration (0.5%). A sample diped in 0.1% surfactant emulsion had 7.7% breakage while that in 0.5% had 9.6%. Higher surfactant concentration appeared to produce a product with slightly more friable texture. This could be due to a greater degree of complexing between surfactant and starch gel in the product, thus reducing number of bonds between starch molecules making it easier to

Table 14

Degree of Breakage of Product Subjected to Various Pretreatments

Treatment	% Breakage[1]
Control (Steam-cooked 10 min, no precooking)	19.3 ± 2.3
Precooking in 200 ppm Ca^{2+}	10.6 ± 0.7
1% Glycerol/30 min	6.7 ± 0.1
5% Glycerol/30 min	5.4 ± 0.3
10% Glycerol/30 min	4.6 ± 1.2
0.1% Surfactant/30 min	7.7 ± 0.5
0.25% Surfactant/30 min	7.1 ± 1.7
0.5% Surfactant/30 min	9.6 ± 0.7
0.1% Surfactant + 5% Glycerol (Combined)	3.6 ± 0.6
0.25% Surfactant + 5% glycerol (Combined)	3.8 ± 0.1

[1]Mean of two samples ± standard error.

break apart.

The combined treatments of surfactant and glycerol significantly reduced the breakage. Soaking of potatoes prior to drying in emulsion of surfactant (0.1%) and glycerol (5%) resulted in lower breakage of finished product i.e 3.6% as compared to dipping in 0.1% surfactant (7.7%) or 5% glycerol (5.4%) alone. This was obviously due to the combined effect of the additives in which the surfactant made the dehydration faster and more complete while glycerol prevented the collapse of cellular structure of the product and rendered it more pliable.

Comparison of the degree of breakage between the lab-prepared and commercial samples could not be made as no such data were available for the commercial product.

4.4 Bulk density

The lab-prepared samples appeared to have a more porous structure and less shrinkage and hence registered lower bulk density than the commercial product (Table 15). The control sample had bulk density of 0.15g/cm^3 as compared to the commercial product of 0.31g/cm^3. To the consumer it means less product is required to rehydrate to a certain quantity as compared to the commercial product. The glycerol treated samples (5 and 10%) were significanly more dense than the control. This was because these products retained slightly more moisture, part of which was replaced by glycerol which is heavier than water.

Samples treated with surfactant, and surfactant and glycerol were found to be even less dense than the untreated samples. Surfactant treated samples dried faster, and therefore retained porous texture resulting in lower bulk density. The porous structure, of course, was also greatly responsible for a faster rate and more complete rehydration of the product. The pliability provided by 5% glycerol, on the other hand, ensured that the product could withstand more vigorous handling during storage and transportation.

TABLE 15

Bulk Density of Commercial and Various Pretreated Hash-brown Potatoes

Predrying Treatment	Bulk Density (g/cm^3)
Commercial sample	0.312
Control (Steam-cooked 10 min, no Ca^{2+})	0.151
Precooking in 200 ppm Ca^{2+}	0.148
1% glycerol/30 min	0.142
5% glycerol/30 min	0.166
10% glycerol/ 30 min.	0.179
0.1% Surfactant/30 min	0.134
0.25% Surfactant/30 min	0.131
0.5% Surfactant/30 min	0.130
0.1% Surfactant + 5% glycerol (Combined)	0.105
0.25% Surfactant + 5% glycerol (Combined)	0.097

4.5 Texture

The results of the textural measurements (shear press with Kramer cell) of rehydrated hash-brown samples are given in Table 16. The product with no precooking treatment was soft and mushy, and required the least force to compress and extrude. Calcium treatment genearally increased the force required. The products without steam cooking treatment were also softer as compared to calcium treated samples. Twenty minutes steam cooking time without calcium pretreatment produced softer product. No significant difference was found between glycerol treated and commercial samples. However, they were significantly softer than the sample precooked in 200 ppm Ca^{2+} and steam cooked for 10 min. Also, samples treated with either glycerol or surfactant alone were softer than those just precooked in 200 ppm Ca^{2+} with 10 minutes cooking, or those with combined treatment of glycerol and surfactant.

In the present investigatiobn, the peak heights of the curve, which were found quite reproduceable, were used as an indication of maximum force required to compress and to extrude the product through the Kramer cell. DeMan (1969) recommended that results of potato texture measurements should be expressed as maximum force divided by sample weight. In determining texture of potato slices, he suggested that measurements should be performed at a constant rate of shear, which should be specified with results. Maximum force is generally considered as an index of the cohesiveness of the food (Voisey, 1971). Cohesiveness is the strength of the internal bonds making up the body of the product (Szczesniak, 1963).

The purpose of this experiment was to find a method to objectively measure and compare the effects of various pretreatments on textural quality of hash-brown potatoes. Mouthfeel or texture is one of the important quality factors of foods. Overall texture is contributed by many attributes. Szczesniak (1963) pointed out two important elements of texture : the physical structure of the material (its geometry) and the way the material handles and feels in the mouth (its mechanical and surface properties). The mechanical characteristics are probably the most important in determining the manner in which the food handles and behaves in the mouth. Most commonly, the measurement of foods is esentially an exercise in

TABLE 16

Results of Textural Measurements (Shear Press) of Rehydrated Hash-brown Potatoes

Sample	Treatment	Maximum Force[1] (Peak height), Kg/25g sample	Maximum Force (Peak height), kg/g sample
I. Control	No precooking, 10 min cooking	6.8[2] ± 0.6	0.272
II. Commercial	-	15.3 ± 0.3	0.612
III. Cooking & precooking treatments	1) No Ca, no cooking	20.9 ± 0.2	0.836
	2) No Ca, 10 min cooking	25.7[2] ± 1.9	1.028
	3) No Ca, 20 min cooking	19.0 ± 1.3	0.760
	4) 200 ppm Ca,[3] no cooking	20.7 ± 3.2	0.828
	5) 200 ppm Ca^{2+}, 10 min cooking	35.0[2] ± 2.3	1.400
	6) 200 ppm Ca^{2+}, 20 min cooking	28.8[2] ± 2.8	1.152
	7) 400 ppm Ca^{2+}, no cooking	19.2 ± 3.9	0.768

contd...

TABLE 16 (contd.)

Results of Textural Measurements (Shear Press) of Rehydrated Hash-brown Potatoes

Sample	Treatment	Maximum Force[1] (Peak height), Kg/25g sample	Maximum Force (Peak height), kg/g sample
	8) 400 ppm Ca^{2+}, 10 min cooking	28.4[2] ± 4.9	1.136
	9) 400 ppm Ca^{2+}, 20 min cooking	22.1 ± 0.1	0.884
IV. Glycerol treatment	1) 1%	23.0 ± 0.7	0.920
	2) 5%	22.9 ± 1.4	0.916
	3) 10%	21.3 ± 0.3	0.852
V. Surfactant treatment	1) 0.1	17.8 ± 1.5	0.712
	2) 0.25	22.8 ± 5.6	0.412
	3) 0.5%	17.0 ± 0.3	0.680
VI. Combined treatments	1) 0.1% Surfactant + 5% Glycerol	29.2[2] ± 4.0	1.168
	2) 0.25% Surfactant + 5% Glycerol	25.8[2] ± 0.5	1.032

[1]Mean of two glycerol samples (each sample with 3 replicates) ± Standard error.

[2]Significant difference at 5% level as compared to commercial sample.

measuring the strength or weakness of the food materials. Most foods are preferred when they are in a structurally weakened state (Bourne *et al.*, 1966). Measurement of firmness of the product is also an important criteria in the evaluation of textural quality of food. Firmness is a measurement of force necessary to attain a given deformation of the sample. Rehydrated hash-brown potatoes are expected to be mealy in texture, yet retain piece integrity on cooking. The maximum force attained (peak height) from the Kramer shear press appears to measure the overall textural property of the product which may include firmness and cohesivenes (Voisey, 1971).

4.6 Product Color

Table 17 provides color readings on the lab-scale (Hunterlab Colorimeter, J. B. Atlas Co. Ltd., Rexdale., Ont.) of a lab-sample and a commercial product, both before and after rehydration. The lab-prepared sample was generally lighter in color than the commercial one. L-values (brightness) of rehydrated samples were significantly higher than dehydrated samples. Lab-sample recorded lower a-values (greenness), and less than half the b-value (yellowness) than the commercial sample. After rehydration, the b-values reduced to about half in both samples.

The particle size of the test materials is of significant importance (Francis and Clydesdale, 1975). In order to increase reproducibility of color readings samples were made more uniform by grinding them to about 420 μm particle size. Effect of the grinding on Hunterlab color values in dehydrated hash-brown potatoes is shown in Fig. 16. The brightness (L-value) of samples increases on grinding. The change in direction of a- and b-values in ground samples was also noticed. This agrees with the results of Bergthaller *et al.* (1983) who found that with increased product fineness, an increase in the brightness (L-value) is observed. After grinding, the b-value decreased in commercial samples, but increased in lab-samples. The trend in the increase of b-values in the range of 250 to 500 μm particle size was also noticed by Bergthaller *et al.* (1983). However, the decrease of b-value in commercial product indicated

TABLE 17

Color Measurement of Hash-brown Potatoes by Hunterlab Colorimeter[1]

	L[2]-Value	a[3]-Value	b[4]-Value
A. Dehydrated			
a) Laboratory Product	75.4 ± 0.5	-2.2 ± 0.2	9.0 ± 0.2
b) Commerical Product	69.2 ± 0.4	-3.4 ± 0.2	21.2 ± 0.2
B. Rehydrated			
a) Laboratory Product	80.4 ± 0.98	-2.5 ± 0.2	5.3 ± 0.3
b) Commercial Product	78.4 ± 0.4	-3.7 ± 0.2	8.4 ± 0.3

[1] Mean of 3 replicates (8 readings each) ± s.d.

[2]L - measures lightness: 100 = perfect white; 0 = black.

[3]a - measures redness: + redness; 0 gray; - greeness.

[4]b - measures yellowness: + yellowness; 0 gray, - blueness.

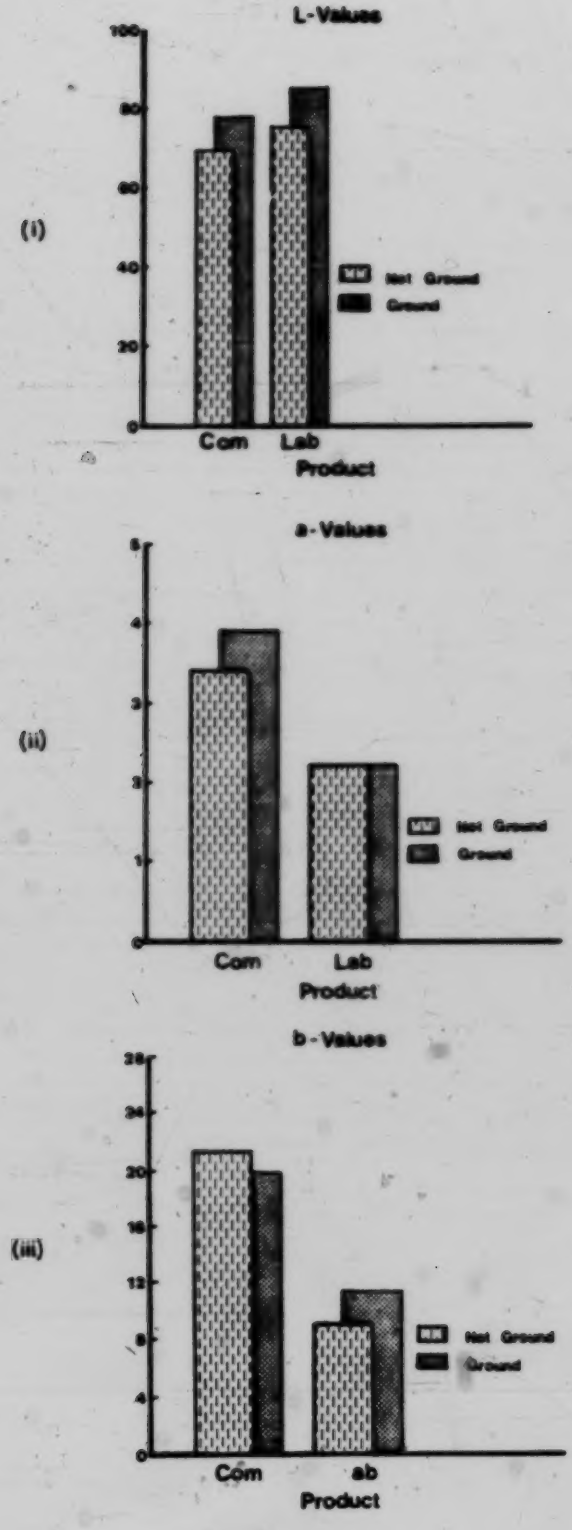


Figure 16. Effect of Grinding on Hunter L-, a-, and b- Values in Dehydrated Hash-brown Samples.

(Com = Commercial sample; Lab = Lab sample; Ground samples = 420 µm particle size.)

that the color pigments were concentrated primarily on the product surface. On grinding, the interior particles of lighter color were exposed to fade the original color, thus reducing the b-value.

The lighter color of the lab-prepared sample is most likely due to a more porous structure and less heat damage as a result of the shorter drying time. Among sensory properties, the color is of particular importance in dehydrated potato products. Color has been considered as an indicator of heat damage (non-enzymatic browning) in dehydrated vegetables (Hendel*et al.*, 1950). Many factors such as raw material (tuber consitutients) and processing conditions play a major role in the reactions which lead to color formation. Browning discoloration which involves enzymatic reaction on the polyphenols, produces reddish-brown to darkbrown pigments on exposure of potato tissue to atmospheric oxygen (Smith, 1975). Large concentrations of tryosine and chlorogenic acid in the potato tissues have a decisive role in this tendency towards coloration. After-cooking darkening or blackening of cooked potato is another discoloration problem which is considered due to the formation of green gray to blue-gray chlorogenic acid - iron (III) complexes (Hughes and Swain, 1962 ; Smith and Davis, 1962). Here, the chlorogenic acid/citric acid ratio is particularly important, since citric acid forms a stable, colorless compound more readily with iron (III) ions (Hughes and Evans, 1967). Non-enzymatic browning reaction produces yellow to yellow-brown pigments during drying and storage due to the participation of amino compounds and reducing sugars (Boyle, 1975; Hendel *et al.*, 1955; Hodge, 1953). All these phenomena contribute to color changes. In the present experiment, SO_2 in the form of sodium metabisulfite was used to check enzymatic and nonenzymatic browning, whereas sodium acid pyrophosphate (SAPP) was added to inhibit after-cooking darkening of the product. These are established practices in dehydrated potato products (Haisman, 1974; Sullivan, 1981; Smith and Davis, 1962).

In the product under investigation, it was noticed from the results of sensory evaluation that browning of potato slices in the preparation of final product (hash-brown potatoes) is a desirable quality. As such, the use of sodium acid pyrophosphate (SAPP) may

not be of significant importance in this particular product. Indeed, it was shown that the color and appearance of the dehydrated product was only slightly changed when the use of the SAPP was terminated.

4.7 Sensory evaluation

In the present investigation, an 8 mm shredder giving approximately (12.7 - 38.1) x 8 x 1.5 mm size shreds, was intially used for making dehydrated hash-browns. It was found in the preliminary sensory test, however, that the product of these dimensions was slightly too thin and had 'rubbery' texture. Therefore, in the subsequent sensory evaluation, the product of bigger dimensions (approx. 25 x 12.7 x 3.2 mm) was used. The results of the sensory evaluation are shown in Table 18. The statistical analysis of these results (Table 19) indicated that panelists differed significantly ($P = 0.05$) in their appraisal of the quality of the samples, possibly because of variation in personal preference towards the product. However, all samples appear to be equally liked resulting in a non significant sample F value. The experimental product was scored very close to the control (hash-brown from fresh potatoes) and commercial samples. The effect of each of the different quality parameters under investigation (texture/flavor/acceptability) was also found to be not significant with respect to the preference of one sample over the other. Correlation analysis also showed no significant relationship between flavor, texture and acceptability, which means neither flavor nor texture of the product appear to influence the panelists in their judgement of its quality.

The difference among the panelists in their perception of the samples may be due to the difference in their concept of an ideal product. Interviews with the panelists revealed that although their method of judging was essentially the same, i.e from the mouthfeel on chewing, their interpretation of the feeling for each characteristics was somewhat different and largely governed by the personal preference on the texture and, to some extent, on the flavor of the product. Most panelists liked 'crisp' but 'mealy' texture of hash-browns. The light brown color of the samples was prefered by the majority of the judges. Desired color of hash browns could

TABLE 18

Results of the Sensory Evaluation of Hash-brown Potatoes[1]

Sample	Characteristics (Attributes)	Panelists											
		1	2	3	4	5	6	7	8	9	10	11	12
I. Control Sample	Texture	7	7	7	4	5	6	6	7	5	7	4	3
(from fresh	Flavor	7	2	8	5	5	8	7	7	5	7	4	3
Potatoes)	Acceptability	7	5	5	6	5	7	6	7	5	7	4	3
II. Experimental	Texture	6	7	7	6	7	6	7	6	5	5	4	2
Product	Flavor	5	3	8	4	5	7	7	8	5	4	4	3
	Acceptability	5	5	5	5	6	6	7	7	6	4	4	2
III. Commercial	Texture	7	7	6	7	7	4	6	5	7	4	2	6
Sample	Flavor	7	2	7	6	5	3	7	7	6	7	4	7
	Acceptability	7	5	4	4	6	3	6	7	7	5	3	7

[1] Scrores on a nine point headonic Scale : 1 being the least acceptable and 9 being the most acceptable.

Table 19

Analysis of Variance of the Results of Sensory Evaluation of Hash-brown Potatoes

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variation Ratio
1. Panelists	11	95.41	8.67	2.27[1]
2. Attributes	2	1.69	0.84	0.33
3. Samples	2	1.46	0.73	0.20
4. Panelists x Attributes	22	56.54	2.57	1.45
5. Panelists x Samples	22	84.10	3.82	2.16[2]
6. Attributes x Samples	4	0.98	0.25	0.14
7. Panelists x Attributes x Sample	44	20.80	0.47	0.27
Total	107	260.98	0.00	

[1] P = 0.05

[2] P = 0.01

be easily achieved by controlling the cooking procedure.

Variation in judgement among panelists may also be due to a tendency of each of the panelists to use either low or high scores on a nine point hedonic-scale. Some judges are more liberal than the others in giving scores, so their scores may be on the high end of the scale, while the more conservative ones may use only the low end of the scale because they normally did not like the hash- brown potatoes.

5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Conclusions

The present investigations show that drying and rehydration characteristics of dehydrated vegetable products such as hash-brown poatatoes may be improved by physical and/or chemical pretreatments. The rate of drying may be increased by precooking the vegetable in $CaCl_2$ solution to strengthen its cell wall and middle lamella, thus preventing excessive shrinkage of the tissue. Drying rate may be further improved by dipping the product in an emulsion of surfactant prior to drying.

The same treatments also improved the rate and completeness of rehydration. The $CaCl_2$ treatment resulted in a product of more porous texture, as compared with a commercial counterpart, while the surfactant facilitates water reabsorption into the product.

Glycerol treatment had little effect on drying and rehydration characteristics but was most beneficial in reducing the degree of breakage of the product during processing, packaging and shipping.

A combined treatment of surfactant (0.1%) and glycerol (5%) has been found best for achieving optimum level of quality characteristics of the dried product, i.e faster drying, faster and more complete rehydration, less breakage, and more desirable texture as compared to the control.

A suggested process flow chart for the production of hash-brown potatoes is shown in Fig. 17.

A few conclusions may, therefore, be drawn from these studies :

1. A fluid-bed dryer, when fitted with a stirrer, can be efficiently used for drying small size vegetable products (after pretreatments) like hash-brown potatoes.
2. The drying time of the process is found very short, i.e one hour, to dry the material from approximately 80% moisture (wet basis) to approximately 6-7%. It is believed that this

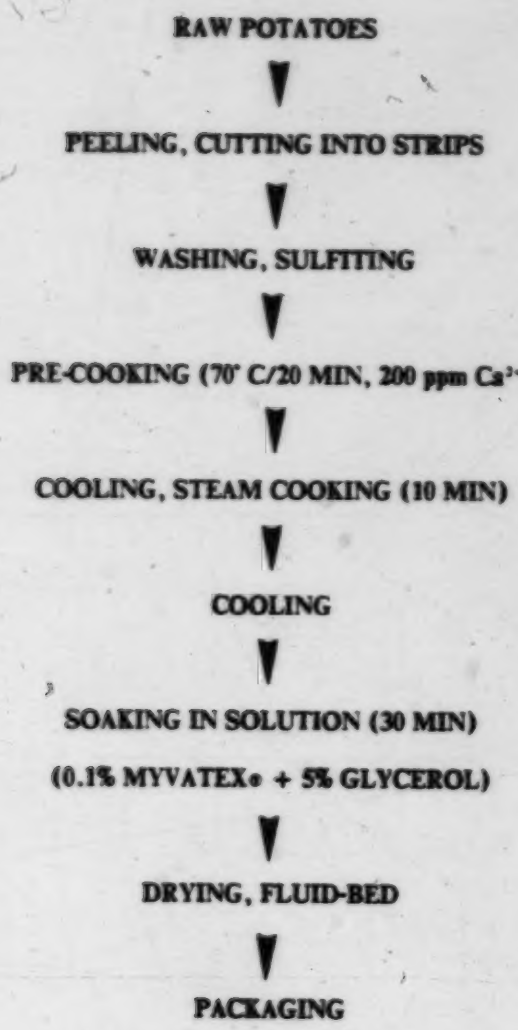


Figure 17. Flow Chart for the Proposed Dehydrated Hash-brown Process.

process could be made continuous on the commercial scale.

3. In this process, $CaCl_2$ and glycerol treatment helped to reduce breakage and made possible the production of thin sliced potato product in a fluid-bed type dryer. Subsequent breakage during packaging and shipping could also be reduced.
4. The experimental product gave faster and more complete rehydration than a commercial sample.
5. The product was found to be lighter in color.
6. The sensory qualities of the lab-product were found similiar to to the product prepared from fresh potatoes and from dehydrated commercial product.

5.2 Suggestions for Future Work

Related to the present work, there are several areas which require further research. These include :

1. Application of present findings to other new type of products, such as ;
   a. Potato rice
   b. Carrot sticks and shoestring carrots
   c. Cauliflower sticks
   d. Dehydrated beet
2. More thorough studies on the effect of each and combined pretreatments on quality characteristics such as textural and sensory evaluation.
3. Detailed investigation on causes and degree of shrinkage of vegetable products during dehydration.
4. Pilot plant studies and economic evaluation of the proposed process.

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